Overview of Needs and Requirements for VNS:

A Volumetric Neutron Source Fusion Facility
to test, develop and qualify Fusion Nuclear Technology
Components and Material Combinations

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Overview of Needs and Requirements for VNS (Volumetric Neutron Source Fusion Facility)

Outline

- VNS Mission and Objectives
- Relationship to ITER and IFMIF
- Framework for FNT Development
- Requirements of Nuclear and Material Testing on VNS Parameters and Design Features
- Reliability Growth Requirements
- Preliminary Test Program in VNS
- VNS Design Concepts
- VENUS Study
- IEA Activity
- Conclusions/Summary

What is the present focus of the World Fusion R&D Program?

- DEMO is the goal of the present world fusion R&D program

Do we have a comprehensive plan to address R&D needs for DEMO?

- It is crucial that we examine the major R&D needs for DEMO and develop R&D strategy that results in:
  - successful development of all key components for DEMO
  - lower overall risk
  - timely development (DEMO operation by the year 2025)
  - cost effective

Major **R&D** Tasks To Be Accomplished Prior to **DEMO**

1) **Plasma**
   - Confinement
   - Divertor
   - Disruption control
   - Current drive

2) **System Integration**

3) **Plasma Support Systems**
   - Magnets
   - Heating

4) **Fusion Nuclear Technology Components and Materials**
   [Blanket, First Wall, High Performance Divertors]
   - Materials combination selection
   - Performance verification and concept validation
   - Show that the fuel cycle can be closed
   - Failure modes and effects
   - Remote maintenance demonstration
   - Reliability growth
   - Component lifetime

ITER will address most of 1,2 and 3

Fusion Nuclear Technology (FNT) components and materials require dedicated fusion-relevant facilities parallel to ITER.

DEMO Characteristics

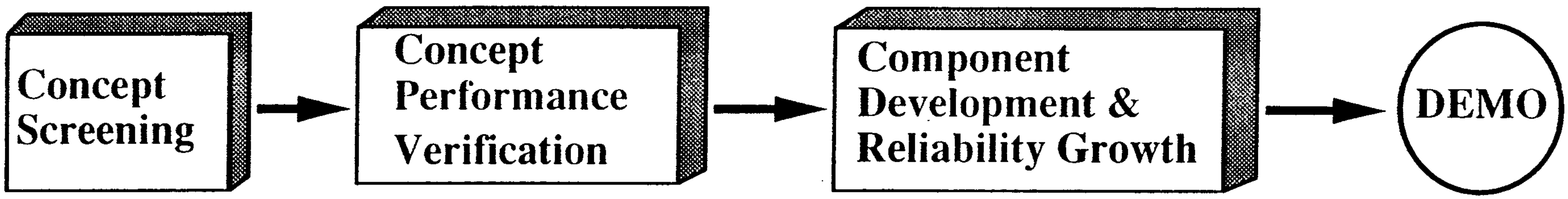
A DEMO Plant is one that demonstrates dependability and reliability. The size, operation and performance of DEMO must be sufficient to demonstrate that there are no open questions about the economics of prototype/first commercial reactor.

Neutron Wall Loading	2-3 MW/m^2
Fluence	10-20 $MW.y/m^2$
Fuel Cycle	Self sufficient, demonstrate doubling time requirements
Plasma Mode of Operation	Steady state (or very long burn, short dwell)
Net Plant Availability	> 50% (Demonstrate reliability and maintainability)

Availability Requirements

- To achieve net plant availability of 50% means that :
  Availability per blanket module > 99%
- Such high availability requirements for blanket module imply that prior to DEMO, there would be aggressive development program for blanket that includes component reliability growth

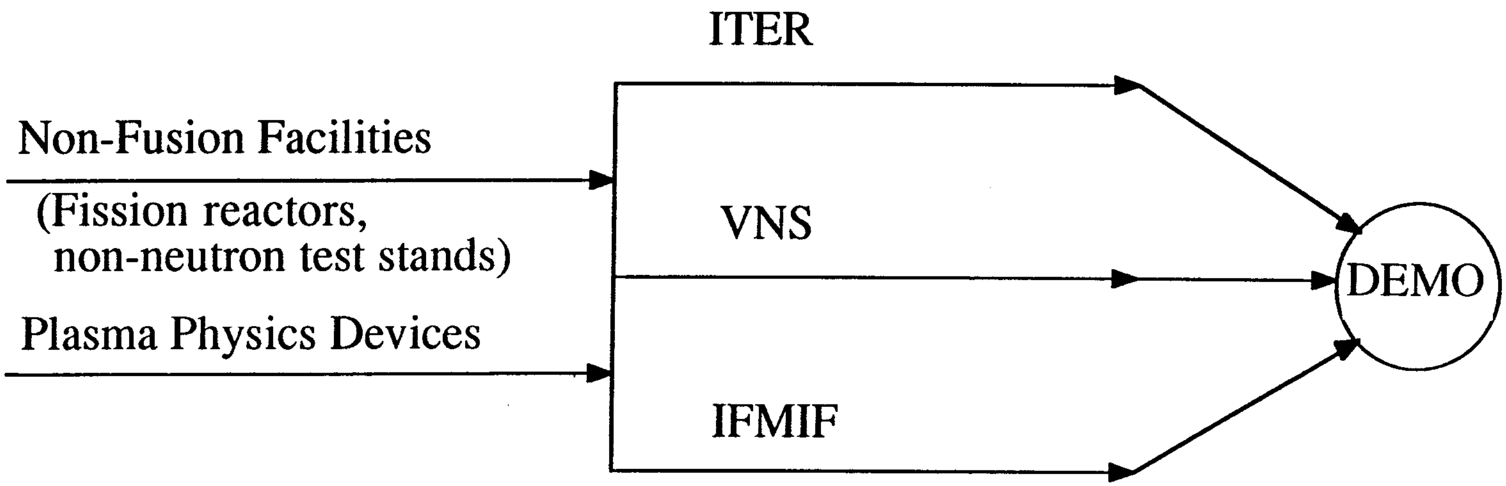
Testing in Fusion Devices For Fusion Nuclear Development Can Be Classified Into a Number of Stages



Required Fluence MW.Y/m^2	0.3	> 1.0	> 4 - 6
Size of Test Article	Submodules	Modules	Modules/Sectors

- Reliability Growth Testing is Most Demanding
  - Requires an aggressive design/test/fix iterative program
  - Requires many test modules and high fluence in fusion facility

Prudent and Optimum Path to DEMO Requires Three Parallel Facilities



<u>ITER</u>

Fusion core (plasma), system integration, plasma support technology

<u>VNS</u> [<u>V</u>olumetric <u>N</u>eutron <u>S</u>ource]

Dedicated fusion facility to test, develop, and qualify fusion nuclear technology components and material combinations [> 10 m3 test volume]

<u>IFMIF</u> ["Point" Neutron Source]

Small volume (<0.01 m3), high availability facility to address radiation effect life time issues

VNS Mission and Objectives

VNS Mission

To complement ITER as a dedicated fusion facility to test, develop and qualify those advanced fusion nuclear technology components and materials combinations that are required for DEMO operation by the year 2025.

FNT components and materials have the highest impact on the economic, environmental and safety attractiveness of fusion energy and they require extensive testing in an integrated fusion environment.

VNS Objectives

Parallel and Sequential Tests of FNT Components and Materials in Submodules, Modules and Sector in Fusion Environment
[neutrons, gamma-rays, surface heat flux, volumetric nuclear heating, magnetic field, tritium, etc.]

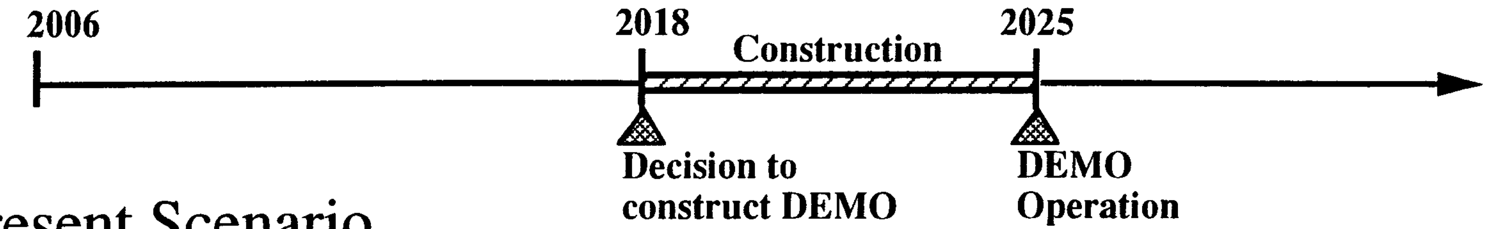
- Calibrate non-fusion tests against performance in the fusion environment
  Check/Validate Codes and Data

- Screen FNT Concepts and Material Combinations

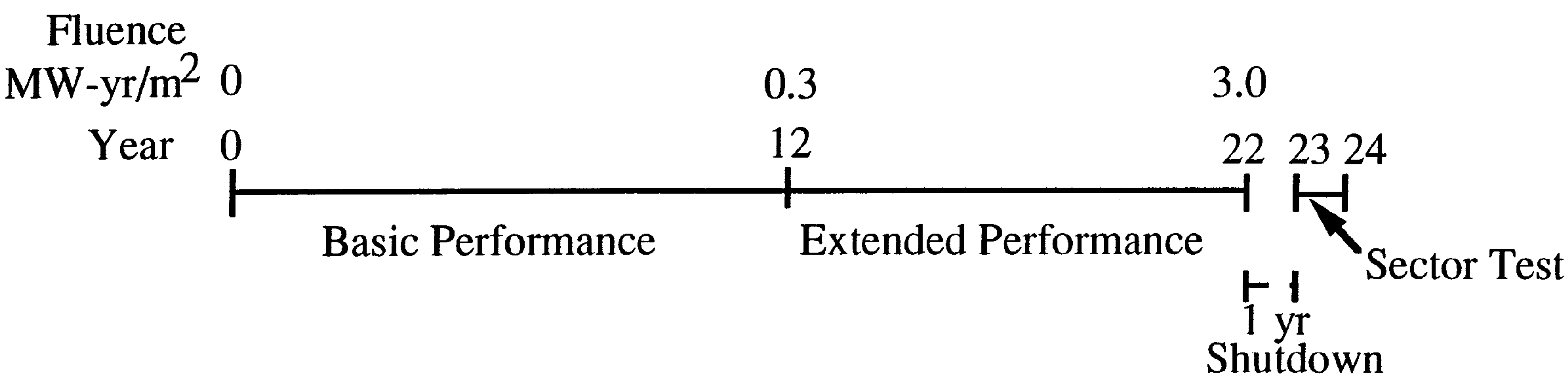
- Performance Verification
  Select Reference Concepts
  Optimize Designs, Verify Performance
  Performance Specific Safety-Related Tests
  Response to off-normal events, operational margin

- Reliability Growth
  - Identify Failure Modes and Effects
  - Iterative design/test/fix programs aimed at improving reliability and safety
  - Failure Rate Data; Obtain Data Base sufficient to predict mean time between failure (MTBF) and component lifetime with sufficient confidence
  - Obtain data base to predict mean time to replace (MTTR) with remote maintenance
  - Obtain sufficient data to predict overall availability of FNT components in DEMO

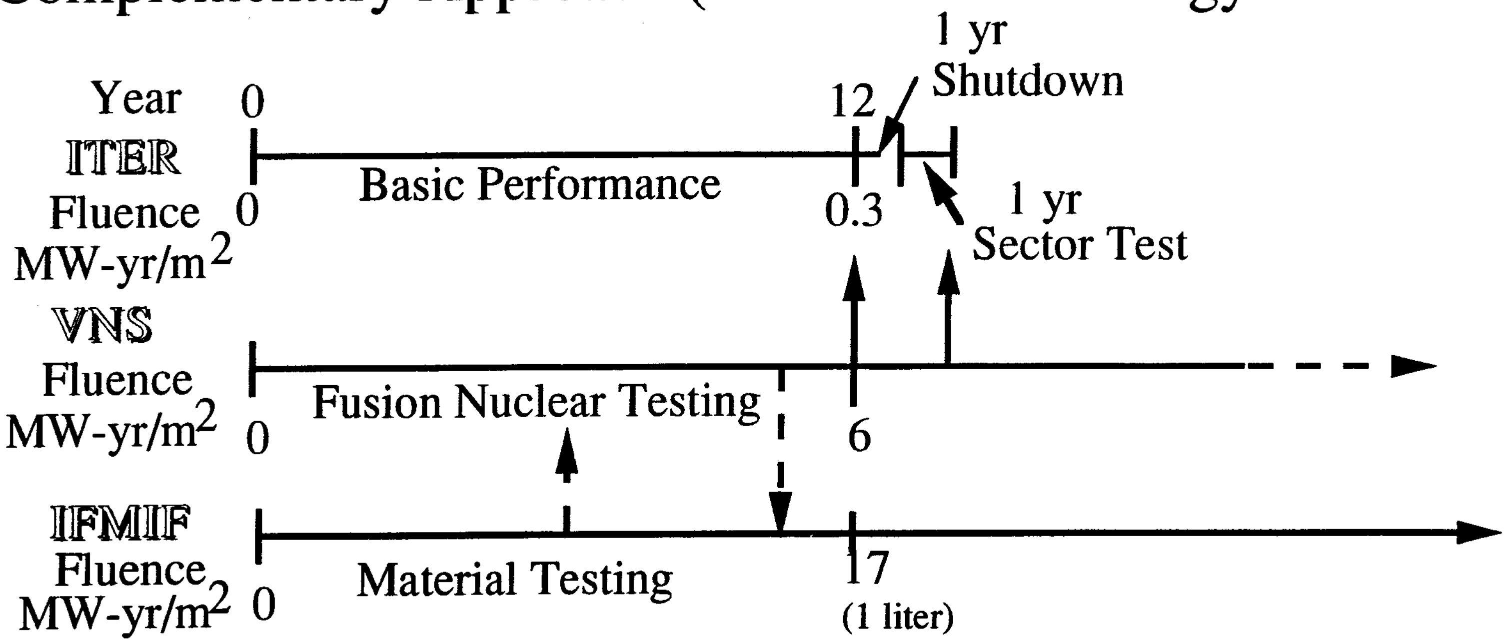
VNS Is Necessary to Meet DEMO Time Schedule



ITER Present Scenario



Complementary Approach (Reduced Technology Burden on ITER)



Physics and Nuclear Technology Requirements for Testing Are Very Dissimilar

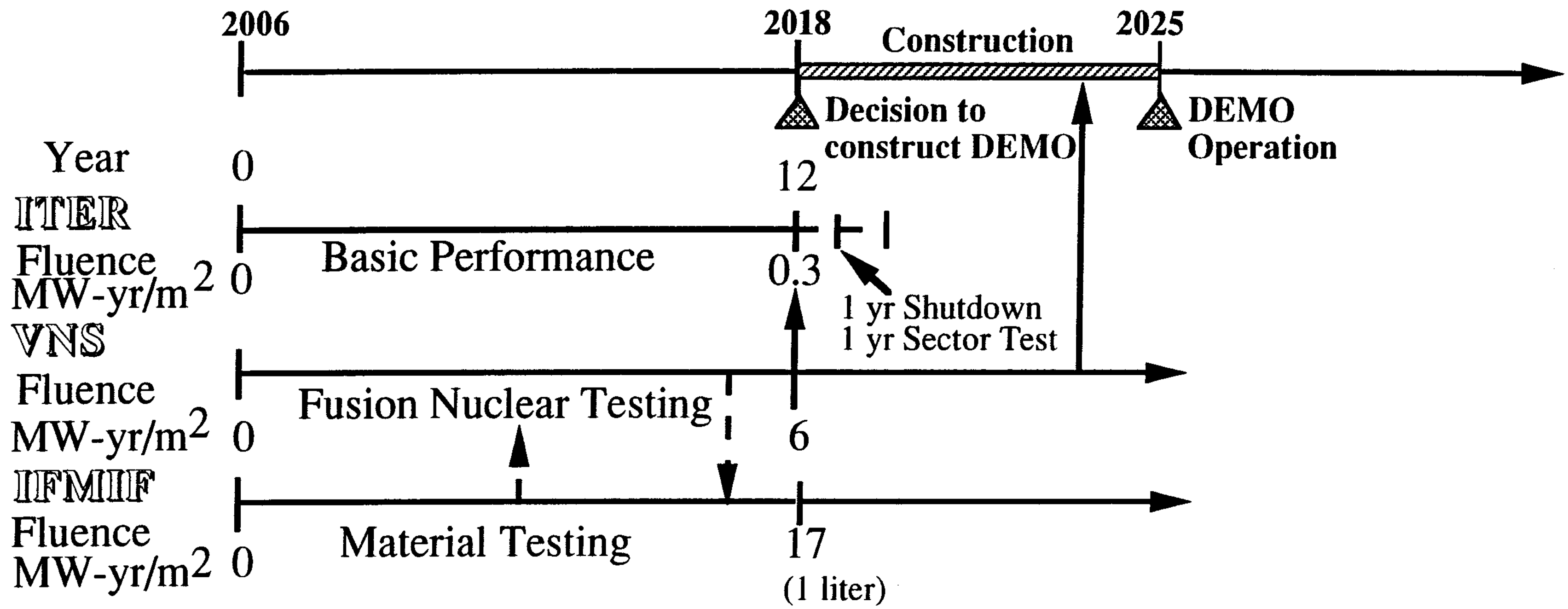
	Fusion Power	Integrated Burn Time	Tritium Consumption
A. Physics and Plasma Support	3500 MW	15 days	8.0 kg
B. Fusion Nuclear Technology	20 MW	5 yr	5.6 kg

Combined * A and B	3500 MW	5 yr	976 kg

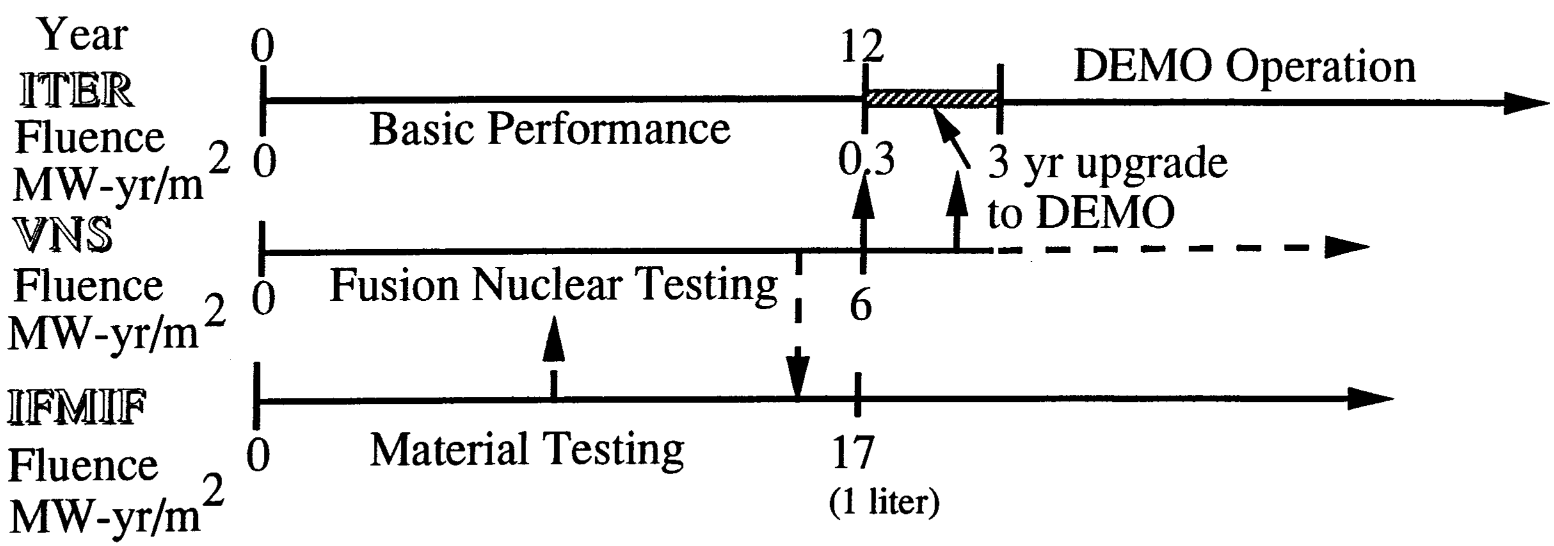
* Combining large power and high fluence leads to large tritium consumption requirements

VNS Increases Confidence in Successful Timely DEMO

Possibility 1



Possibility 2 (Very High Success Scenario)



MAJOR DEVICE PARAMETERS OF FUSION FACILITIES

	ITER	VNS	IFMIF*
Availability	10 %	30%	>70%
Wall Load, (MW/m^2)	2	1–2	$2^{(a)}$
Fluence @12yr, ($MW{\cdot}yr/m^2$)	0.3	6	17
Test Area [Volume)]	TBD	$>30m^2$ [$15m^3$]	$<0.02m^2$ [$0.001m^3$]$^{(b)}$
Cost Goal (relative units)	1	0.3	0.1

*Source: IAE Workshops (1989, 1992)

(a): 2 at 1 liter; 5 at 0.1 liter; 10^{15} n/cm^2–s; E_n>0.1MeV
(b): at $2MW/m^2$

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M. ABDOU: VENUS–3 . 7/93

Role of Major Fusion Facilities

ITER	VNS	IFMIF
Limited Fluence	Medium Fluence, Large Volume	High Fluence, Small Volume
• Plasma Fusion Core • Tokamak System Integration •Plasma Support Technology • Testing of Nuclear Components - Limited Fluence - Sector-Type Tests	• Dedicated Tests for fusion nuclear component and material combinations - Calibrate non-fusion tests on component behavior - Validate codes - Screen material combinations - Concept screening - Concept validation [Testing in submodules, modules with all environmental conditions] • Aggressive reliability growth program to meet availability goals for nuclear components in DEMO	• Accelerated Tests of 14 MeV neutron damage effects on material properties (Primarily structural materials) • Calibrate non-fusion tests on neutron radiation effects on structural materials • Material property improvement

VNS and IFMIF Complement Each Other

IFMIF will concentrate on lifetime neutron radiation effects in small limited volume (and limited time)

VNS will screen materials by testing material combinations in subcomponents scale with neutrons and other environmental conditions such as coolant conditions, welds, mechanical joints, effects of temperature, stress and damage gradients on large structures, clad/breeder interaction, fatigue, thermal cycling, etc.

- VNS will help IFMIF conserve space and time by screening materials based on performance of material combinations in sub-components-scale tests in integrated environment

- IFMIF will help VNS eliminate design choices with structural materials that have severely limited lifetime under neutron radiation effects.

ITER Fluence Scenario (Preliminary)

Year	Plasma	Neutron Wall Load Average	Neutron Wall Load on Port	Required Burn Time/yr (duty cycle × A)	Accumulated Fluence Average	Accumulated Fluence on Port
Basic Performance						
1	H D	0	0	0	0	
2	H D, D ^{3}He	0	0	0	0	
3	D T	2.0	2.8	0.005	0.01	0.014
4	D T	2.0	2.8	0.005	0.02	0.028
5	D T	2.0	2.8	0.01	0.04	0.056
6	D T	2.0	2.8	0.01	0.06	0.084
7	D T	2.0	2.8	0.02	0.1	0.14
8	D T	2.0	2.8	0.02	0.14	0.20
9	D T	2.0	2.8	0.025	0.19	0.27
10	D T	2.0	2.8	0.025	0.24	0.34
11	D T	2.0	2.8	0.03	0.30	0.42
12	D T	2.0	2.8	0.03	0.36	0.50
Extended Performance						
13	D T	2.0	2.8	0.1	0.56	0.78
14	D T	2.0	2.8	0.1	0.76	1.06
15	D T	2.0	2.8	0.1	0.96	1.34
16	D T	2.0	2.8	0.125	1.21	1.7
17	D T	2.0	2.8	0.125	1.46	2.0
18	D T	2.0	2.8	0.15	1.76	2.5
19	D T	2.0	2.8	0.15	2.06	2.9
20	D T	2.0	2.8	0.15	2.36	3.3
21	D T	2.0	2.8	0.15	2.66	3.7
22	D T	2.0	2.8	0.15	3.0	4.2
Shutdown, Maintenance Demonstration						
23–24		0	0	0	3.0	4.2

VENUS Fluence Scenario [Example]

Year	Plasma	Neutron Wall Load (MW/m²) Average	Neutron Wall Load (MW/m²) on Port	Required Burn Time/yr (duty cycle × availability)	Accumulated Fluence (MW-yr/m²) Average	Accumulated Fluence (MW-yr/m²) on Port
Physics Checkout, Divertor Testing						
1	HD	0	0	0	0	
2	DT	1.0	1.4	0.05	0.05	0.07
Screening Phase						
3	DT	2.0	2.8	0.1	0.15	0.2
4	DT	2.0	2.8	0.15	0.3	0.5
Performance Verification						
5	DT	2.0	2.8	0.2	0.7	1.0
6	DT	2.0	2.8	0.2	1.1	1.5
7	DT	2.0	2.8	0.3	1.7	2.4
8	DT	2.0	2.8	0.3	2.3	3.2
9	DT	2.0	2.8	0.3	2.9	4.1
Reliability Growth						
10	DT	2.0	2.8	0.3	3.5	4.9
11	DT	2.0	2.8	0.3	4.1	5.7
12	DT	2.0	2.8	0.3	4.7	6.6
13	DT	2.0	2.8	0.3	5.3	7.4
14	DT	2.0	2.8	0.3	6.0	8.4

Benefits of VNS

Primary

Makes it possible to develop with reasonable confidence FNT Components and Material Combinations that meet the DEMO Performance Technical Requirements (particularly reliability/availability) with a self-consistent time schedule

Other Benefits

- Reduced Technological Risk and Cost to ITER
  - -Reduce Fluence need
  - -Eliminate Need for Breeding Blanket

- Provides additional experience in design, construction and licensing of a fusion device

- Forcing Function to developments concerned with remote maintenance and component reliability

Nuclear Testing Requirements

- ## Engineering Scaling Requirements

	Minimum	Highly Desirable
Neutron Wall Load (MW/m^2)	1	2
Plasma Burn Time	> 1000 s	Steady State (or long burn, hours)
Dwell Time	a	< 20 s
Continuous Test Duration (steady state or back-to-back cycle 100% availability)	> 1 week	2 weeks
Average Availability	10 - 15 %	25 - 35 %
Total Neutron Fluence ($MW\text{-}a/m^2$)	1.5	4 - 6
Test Port Size (m^2 x m)		
Module	0.5 x 0.3	1 x 0.5
Outboard Sector	2 x 0.5	4 x 0.8
Total Test Area (m^2)		
Module Only	5	10 - 20
Including Outboard Sectors	7	20 -30

- ## Programmatic Constraints

Test Time	12 yr
Fluence	6 $MW\text{-}yr/m^2$
Neutron Wall Load	2 MW/m^2

Duty Cycle x Availability	30 %

TABLE 1. Preliminary Testing Requirements on Key Parameters of VNS

Wall Load
- Minimum: > 1 MW/m^2
- Substantial benefits: 2–3 MW/m^2
- Much higher wall loads can be beneficial and will alter strategy (accelerated testing, more ambitious technology performance goals for fusion, etc.)

Surface Heat Load
- Critical for tests of first wall, solid breeder blankets, liquid-metal blankets
- Critical: > 20 W/cm^2
- Important: > 40 W/cm^2
- Methods to enhance surface heat flux in fusion test facilities are important

Plasma Burn Cycle
- Pulsing sharply reduces the value of many tests
- Minimum burn time: > 1000 s
- Maximum dwell time: < 100 s
- Prefer steady state

Minimum Continuous Time
- Many periods with 100% availability
- Duration of each period
  Critical: Several days
  Important: Several weeks

Availability
- Minimum: 20%
- Substantial benefits: 50%

Fluence
- Fluence requirements will depend on whether a neutron source or other means is available for high fluence material testing
- In general, component tests in the early stages of development are carried out to fluences lower than those for specimen
- In all cases, higher fluences are desirable but costly; modest fluence are still extremely valuable
- For component tests:
  Critical: 1–2 $MW\text{-}yr/m^2$
  Very important: 2–4 $MW\text{-}yr/m^2$
  Important: 4–6 $MW\text{-}yr/m^2$
  Desirable: 6–10 MW-yr/m

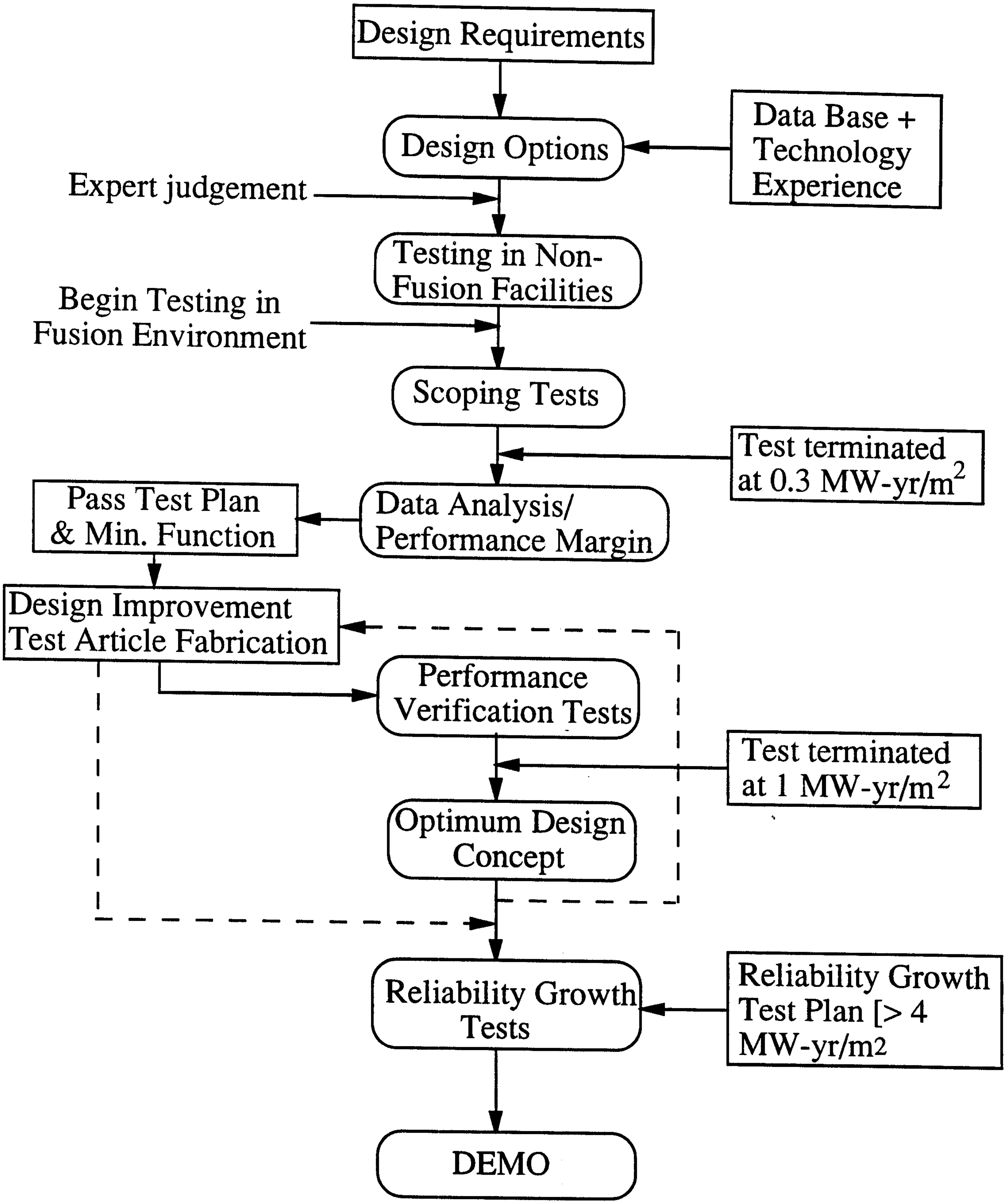
Minimum Size of Test Assembly
- Interactive tests: ~ 0.2m×0.2m×0.1m
- Integrated tests: ~ 1m×1m×0.5m

(Some liquid-metal blanket designs tend to require larger size, sector scale)

Test Surface Area
- Critical: > 5 m^2
- very important: > 10 m^2
- Important: 15–20 m^2
- Desirable: 20–30 m^2

Magnetic Field
- Critical: > 3 T
- Important: > 5 T

Fusion Nuclear Technology Development Approach



RELIABILITY GROWTH

Some Considerations in Developing Reliability Test Program For Blanket

Achieving A High Plant Availability Requires A Very High Blanket Availability

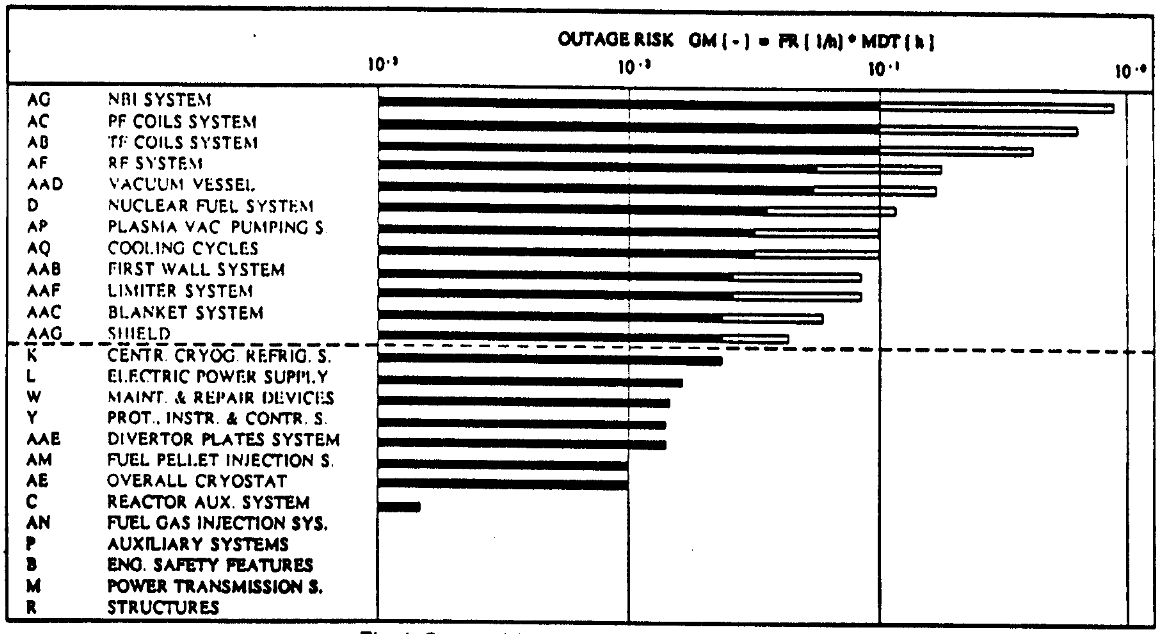


Fig. 4. Outage risk contributions of components.

- The outage risk is defined as, failure rate x mean down time, which gives the availability being equal to $\frac{1}{1+\text{outage risk}}$
  Plant outage risk = 0.717; Plant availability = 58%
  Blanket outage risk = 0.024 ; Blanket availability = 97.6%
- Failure rates for various components were from industrial engineering, processing engineering and nuclear power plant, etc.
- Components above line require improvement in failure rate data to achieve target values, components below line require verification of failure rate data.

Reference: R. Buende, "Reliability and Availability Issues in NET," Fusion Engineering and Design 11 (1989) 139-150

Requirements on Blanket Availability as a Function of Plant Availability

Plant Availability	Blanket Availability
75 %	> 99 %
58 %	97.6 %
55 %	90 %
51 %	80 %
37%	50 %

Blanket Module Availability vs Blanket System Availability

- The overall availability of a blanket system (BS), A_{BS}, is written as:

$$A_{BS} = \frac{MTBF_{BS}}{MTBF_{BS} + MTTR_{BS}} = \frac{1}{1 + \lambda_{BS}\, MTTR_{BS}}$$

where

$MTBF_{BS}$	=	Mean time between failures of the blanket system
$MTTR_{BS}$	=	Mean time to replace the blanket system
λ_{BS}	=	Failure rate of blanket system

and $$\lambda_{BS} = \frac{1}{MTBF_{BS}}$$

- In general, a blanket system consists of a series of modules. This implies that the failure rate of the blanket system is equal to:

$$\lambda_{BS} = n\ \lambda_n$$

and $$A_{BS} = \frac{1}{1 + \lambda_{BS}\, MTTR_{BS}} = \frac{1}{1 + n\lambda_n\, nMTTR_n}$$

where

n	=	# of modules (A module is the smallest physical element that can be replaced when a failure occurs.)
λ_n	=	Failure rate per module
$MTTR_n$	=	Mean time to replace a module (approximated as that of a sector, i.e. $MTTR_n = MTTR_N$)

- Note that to replace a module, it is probablly needed to pull out a sector, then pull out the module from the sector

i.e. $$MTTR_n \geq MTTR_N$$

- A Blanket Module Availability (A_n)

$$A_n = \frac{1}{1 + \lambda_n MTTR_n}$$

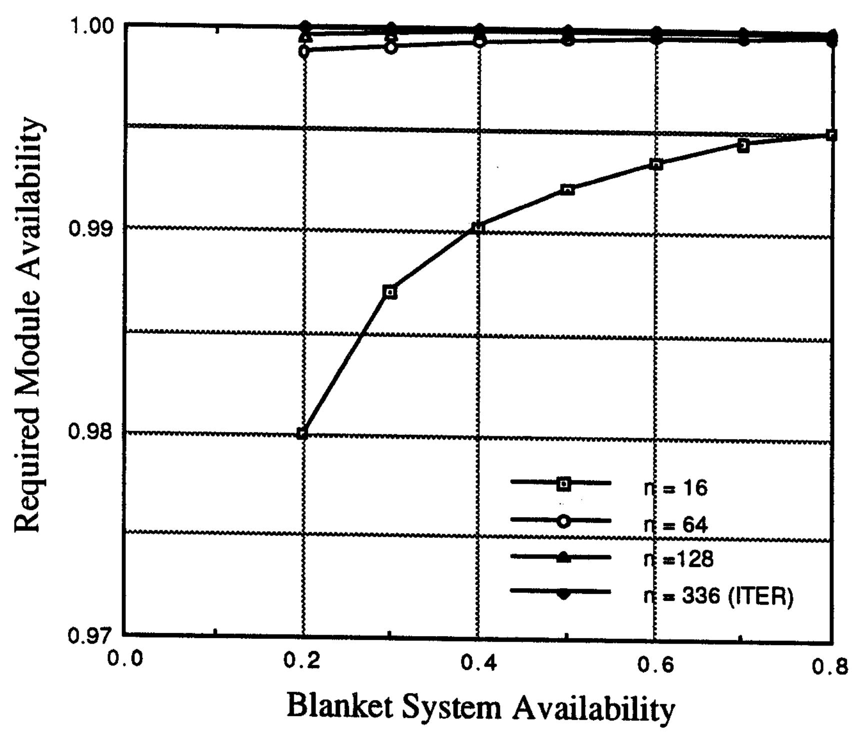
Achieving a High Blanket Availability Requires A Very High Module Availability

- A Blanket System Availability (A_{BS})

$$A_{BS} = \frac{A_n}{A_n(1-n^2)+n^2} \approx \frac{A_n}{n^2(1-A_n)} \qquad (n^2 >> 1)$$

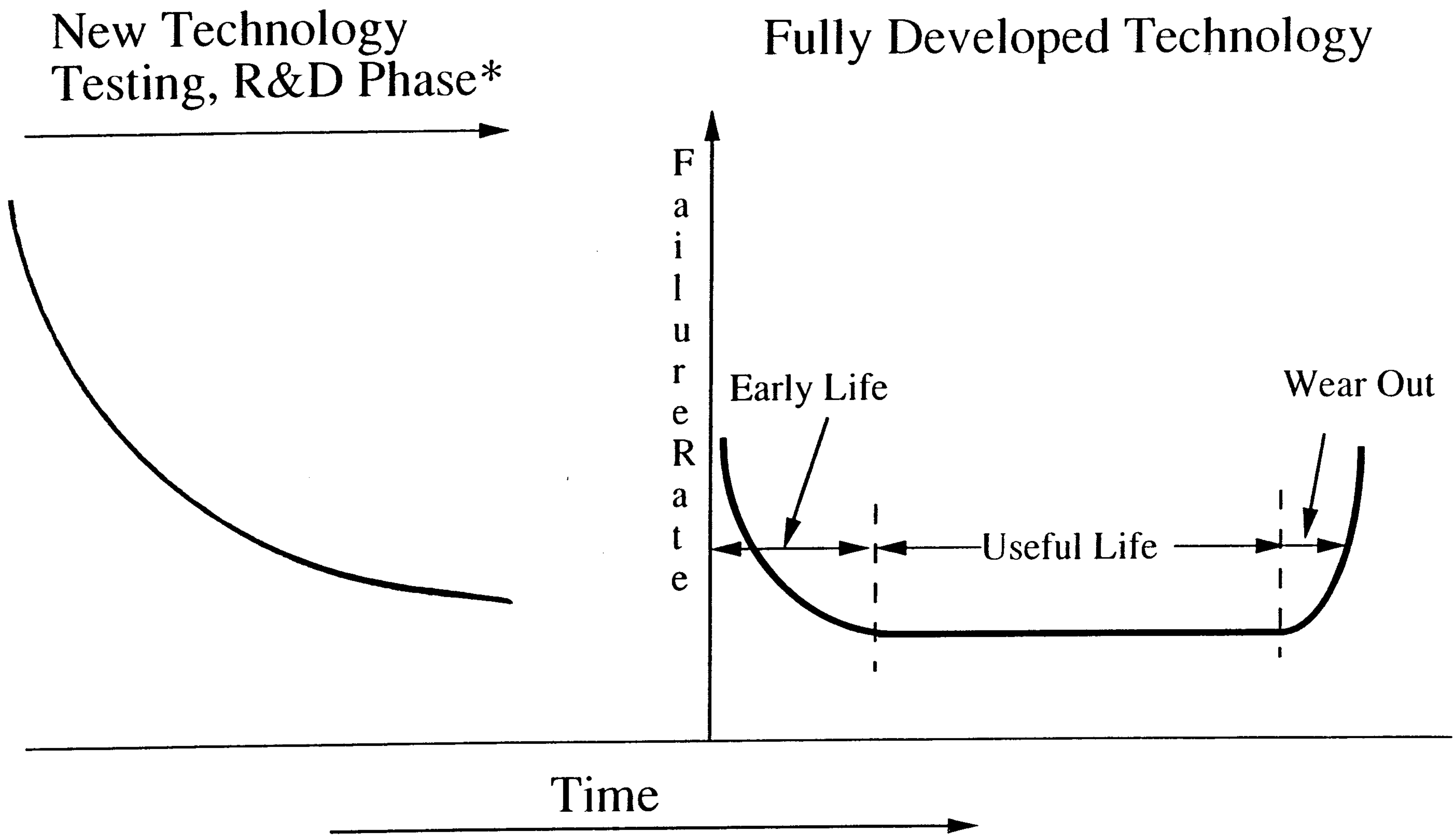
or

$$A_n \approx \frac{1}{1 + \frac{1}{n^2 A_{BS}}}$$



MTTRn	Required MTBF (Years)			
	ABS = 0.5		ABS = 0.8	
	n = 16	n = 336	n = 16	n = 336
1 day	0.35	155	0.56	247
1 week	2.5	1084	3.9	1728

Schematic Failure Rate vs Time During Development and After Development



*The curve shown is for an aggressive development program.

FAILURE IS DIFFERENT FROM DESIGN LIFETIME

Definition

Failure is defined as the ending of the ability of a design element to meet its function before its allotted lifetime is achieved, i.e. before the operating time for which the element is designed is reached.

Causes of Failures

- Errors in design, manufacturing, assembly and operation
- Lack of knowledge and experience
- Insufficient prior testing
- Random occurrence despite available knowledge and experience

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Estimated Failure Frequencies for ITER In-Vessel Blanket System

Event/Failure Mode	Failure Rate	Length or Number of Welds	Failure rate /hour	MTBF	Frequency per FPY
In-Vessel LOCA	[1a] 5E-08 /(h-m)	[2] Tube length close to the FW = 46 km	2.3E-3	431 hours	20
	[1b] 3.3E-08/(h-m)	[3] Overall blanket tube length= 159 km	5.3E-3	189 hours	46
Butt Welds of Pipes [4]	[a]1E-07/(h-weld)	[5]158,976 welds	1.59E-02	63 hours	139
	[b]1E-08/(h-weld)		1.59E-03	629 hours	14
	[c]1E-09/(h-weld)		1.59E-04	6290 hours	1-2

1 From L. Cadwallader, "Investigation of Selected Accident Frequencies for Helium, Water, and Liquid Metal ITER Coolants," ITER/US/93/EN/SA-3.

- Estimated leak failure rate for copper tubes (including brazes) was about 5E-07/hour-m in the first wall and divertor areas.

a - For steel pipe failure rate, the above number is reduced by a factor of 10. This gives a steel pipe leak failure rate of 5E-08/hour-m.

b - This failure rate is about 1/3 lower than the failure rate estimated for the FW to account for less radiation effect.

2. The total tube length close to the first wall is estimated as: 12 m/tube x 7 tubes near the FW/module x 552 modules = 46368 m.
3. This tube length is estimated as: 12 m/tube x 24 tubes per module x 552 modules =1.59E5 m.

4. From R. Bünde et al., "Reliability of Welds and Brazed Joints in Blankets and Its Influence on Availability," Fusion Engineering and Design, 16 (1191) 59-72.(a. upper value b. reference value c. upper value). Note that these failure rates were estimated for the useful life period, the failure rate during the infant mortality period would be much higher.
5. Number of welds was estimated for the ITER JCT He-Cooled blanket (duplex tubing) design by V. D. Lee. The assumption was 1 weld for tube entering blanket at top, 1 for tube turning down blanket, 1 for tube turnaround at bottom and 2 manifold welds at top.

FAILURE RATE

References (extremely limited)

- R. Bünde, et. al ISFNT-1 (Fus. Eng. & Design 1989)
  ISFNT-2 (Fus. Eng. & Design 1991)
  Other (unpublished work)
- L. Cadwallader, INEL (LOCA and LOFA, ITER memo Jan. 1993)

- Data in these and other references are based on well established technologies (mostly fission reactors and steam generators) for the bottom of the bathtub failure rate curve (i.e. after all learning in hundreds to thousands of units and "unit•time" equivalent to thousands of years of operating experience).

- Based on this data, a representative First wall/Blanket in the present ITER design is estimated to have (see detailed estimate)

"Base" Failure Rate ~ 10-50 per year of operation (per FPY)

- However, for ITER as the first fusion device (new technology), the failure rate during the first several years of operation can be higher by one to two orders of magnitude (or more depending on design and prior testing).

Expected Failure Rate in FW/B can be on the order of 100-500 per FPY

WHY EXPECTED FAILURE RATE IN ITER FW/B DURING EARLY YEARS OF OPERATION COULD BE MUCH HIGHER THAN BASE CASE ESTIMATES

<u>Base Estimate Failure Rate (FR) Assumptions</u>

- Mature well developed technology (fission reactors, steam generators, etc.)
- Bottom of bathtub of FR vs. operating time curve

<u>Expected FR Estimate for ITER Early Years</u>

Failure rate could be much higher because:

1) New Technology
   - No prior experience in actual system
   - Initial failure rate is higher by factors of 10 to 100 than bottom of bathtub
   - Prior testing is severely limited in simulating fusion environment

2) Fusion FW/B is More Complex than Steam Generators and Fission Core

   - Larger number of sub components and interactions (tubes, welds, breeder, multiplier, coolant, structure, tritium recovery, etc.)
   - More damaging higher energy neutrons
   - Other environmental conditions: magnetic field, tritium, vacuum, etc.
   - Reactor components must penetrate each other
   - Ability to have redundancy inside FW/B system is extremely limited

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REMARKS ON FAILURE RATE AND RELIABILITY GROWTH

- Capability to replace first wall and blanket (individual modules as well as the entire FW/B system) in a reasonable time MUST be a design goal for fusion devices

- Design concepts for FW/B (and other components) must aim at improving reliability. One of the most effective directions is to minimize features that are known to have high failure rate (e.g. minimize or eliminate welds, brazes, tube length)

- A serious reliability and availability analysis must be an integral part of the design process

- R&D program must be based on quantitative goals for reliability (type of tests, prototypicality of test, number of tests, test duration)

- Reliability growth testing in fusion devices will be the most demanding (particularly on number of tests and time duration of tests). Reliability testing should include:
  - Identification of failure modes and effects
  - Aggressive iterative design/test/fix programs aimed at improving reliability
  - Obtain failure rate data sufficient to predict MTBF

Reliability Testing: General Background

- Sequential Tests

- When this test is performed, no decision is made in advance as to the number of hours to be used for test. The accumulated results of the test at any point serve as a criterion for making one of three possible decisions:
  - Accept the component
  - Reject the component
  - Continue testing

- MIL-STD-781 : A military standard for equipment reliability testing issued by DOD in 1967.

- The test plans may be used for both reliability demonstration tests (qualification) and reliability production acceptance tests (sampling).

- Based on this plan, INTOR concluded that the achievement of 80% confidence in a given component mean time between failures (MTBF) in the constant failure rate regime of operation would typically require a cumulative test period of 3.5 times the MTBF. (i. e. 3.5 ≈ (7.6+ 2.4 + 1.14) / 3.)

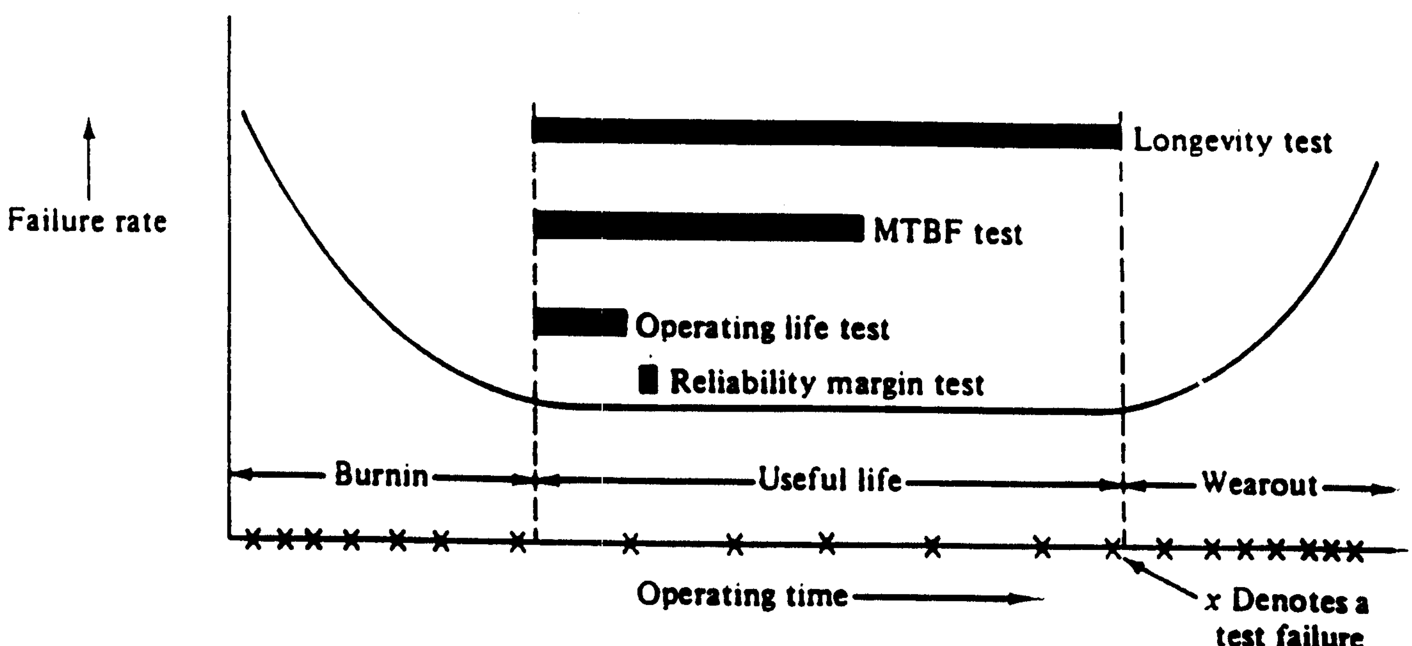
TABLE XII.4-5. SUMMARY OF MIL-STD-781 SEQUENTIAL TEST PLANS

MIL-STD-781B Test Plan	Decision Risks α and β (%)	Discrimination Ratio = θ_0/θ_1	Time to Decision (in Units of MTBF)		
			Minimum (for MTBF > θ_1)	Expected (for MTBF = θ_0)	Maximum (Truncated)
I	10	1.5	4.40	17.3	33.00
II	20 ✓	1.5	2.79	7.6 ✓	14.60
III	10	2.0	2.20	5.1	10.30
IV	20 ✓	2.0	1.40	2.4 ✓	4.87
IVa	20 ✓	3.0	0.89	1.14 ✓	1.50
V	10	3.0	1.25	2.0	3.45
VI	10	5.0	0.55	0.64	1.25
VII	30	1.5	2.10	3.4	4.53
VIII	30	2.0	0.86	1.3.	2.25
IX	35,40	1.25	2.00	5.0	8.25

Reliability Tests

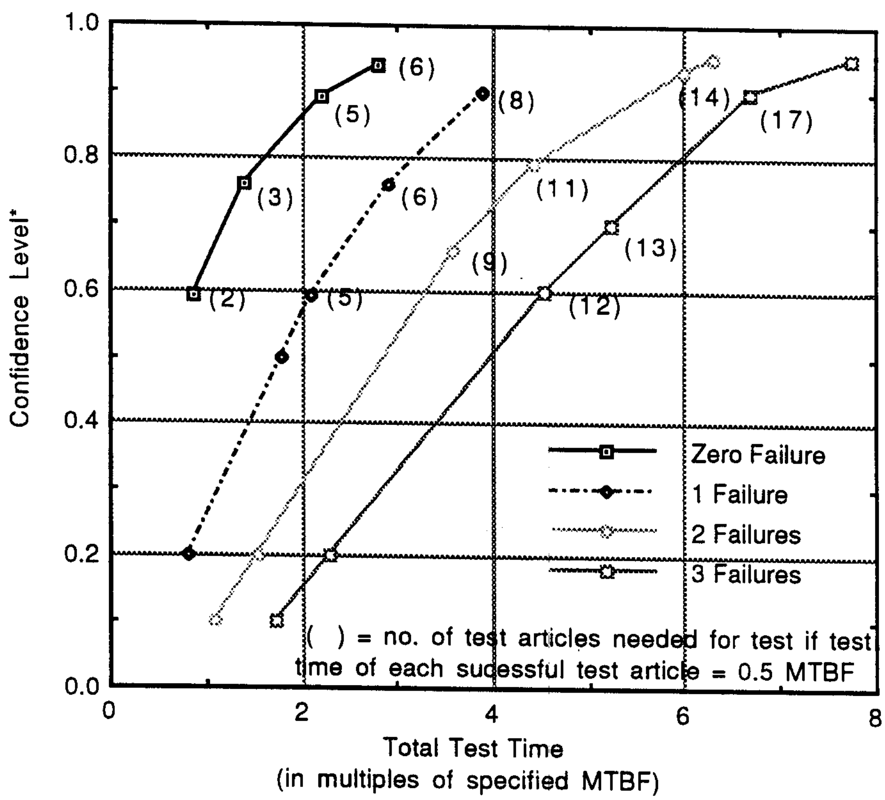
- Objectives
  - Determining if design improvement is needed to meet the reliability requirement.
  - Indicating if any design changes are needed and verifying improvements in design reliability.
  - Determining if a part, assembly, and subsystem should be accepted or rejected (on an individual or lot basis).
  - Determining if a given design is truly qualified for its intended application.
  - Providing data which indicate necessary modifications or operational procedures and policies, especially as they influence reliability and maintainability.

- Types of Reliability Tests
  1. *Longevity tests* measure or demonstrate the duration of the useful life phase.
  2. *MTBF tests* measure mean time between failures.
  3. *Operating life tests* measure ability to perform without failure for a prescribed minimum period.
  4. *Reliability margin tests* measure the margin of safety between the extremes of operating environments and the limits of ability of the equipment to withstand these environments.



Test Time and Number of Test Articles vs Confidence Level

- For MTBF tests, the minimum test time per component = 0.5 MTBF (assuming that the component useful operating time is equal to the MTBF)
- This requirement implies that 6 test components are needed for achieving a 90% confidence level, if the number of failure is zero.
- With 1 failure during the test, the number of test articles would be 8 for achieving a 90% confidence and 7 for 80% confidence.

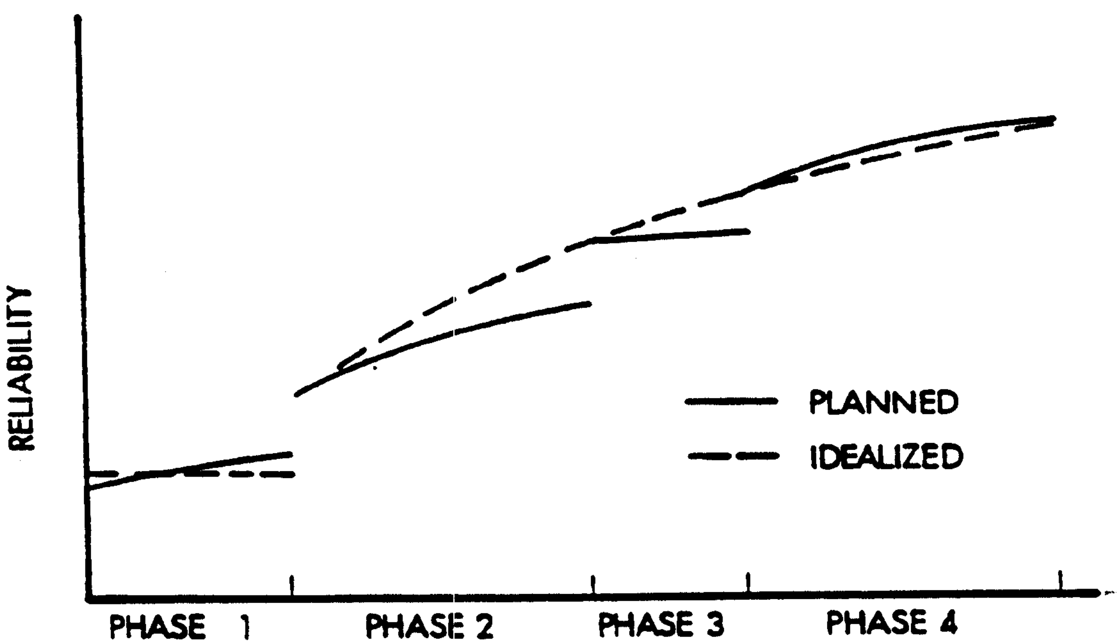


* Confidence level 0.8 means that the confidence of the lower limit on the MTBF being equal to the specified MTBF is 80%.

Reliability Growth Curve : Implication

- In planning the reliability growth, the major role of the idealized curve (such as constructed based on Duane's model) is to quantify the overall development effort so that the growth pattern can be evaluated relative to the basic objectives of the program.
- The planned growth curve lays out a more detailed plan of how the reliability growth will actually be achieved.
- The jump in reliability at the end of test phase reflects the incorporation of fixes at the end of test phase and before the next testing period.

Example of Planned Growth Curve and Corresponding Idealized Curve



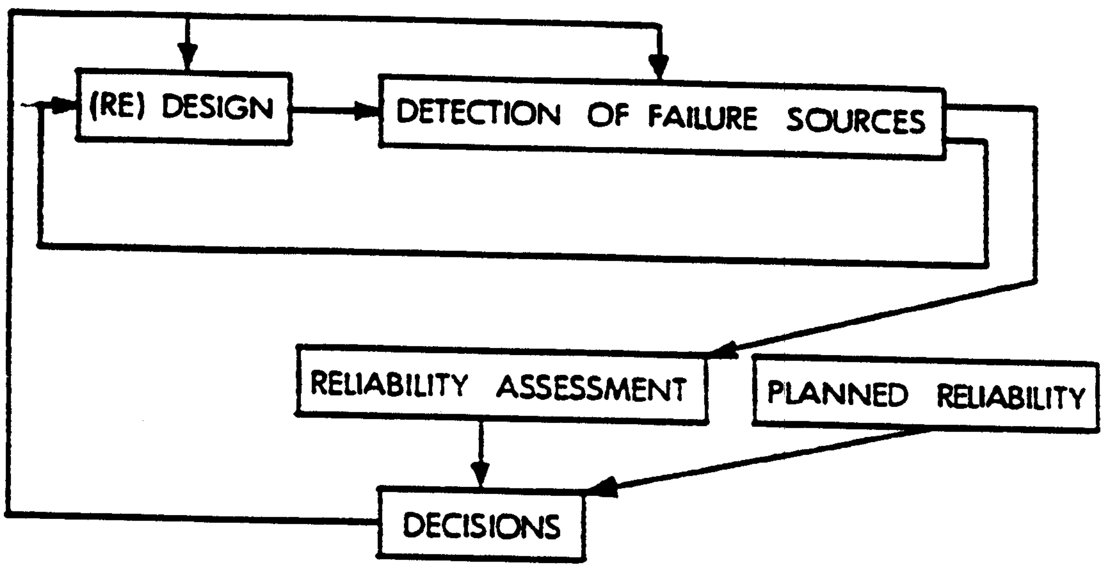
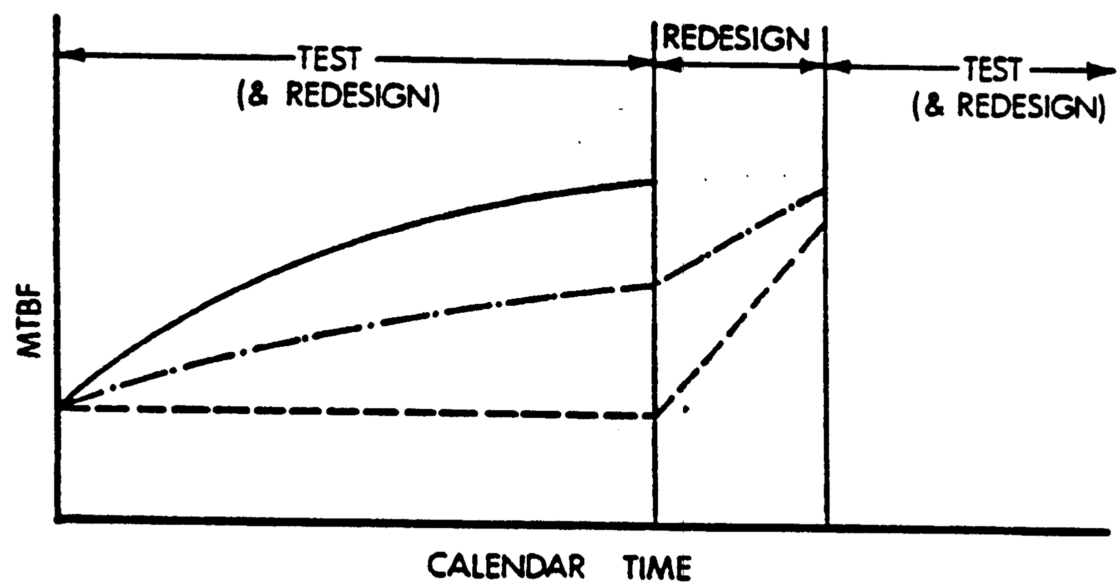


Figure 4.2 Reliability Growth Management Model (Assessment).



LEGEND:

———	ALL REDESIGN DURING TEST PHASE,	NONE DURING REDES. PH.
—·—·—	SOME " " " " ,	SOME " " "
– – – –	NO " " " " ,	ALL " " "

Figure 5.29 Effect of Deferring Redesign.

Reliability Growth :Background

- A discipline used to investigate the cause of each failure, and redesign to try to make sure it will not reoccur (a process known as test, analyze and fix).

- Past experience on reliability growth testing (non-fusion, a large variety of equipment such as pump) has shown that the rate of increase in the MTBF (M) of component can be expressed as(Duane Model):

$$M = A\,t^{\alpha}$$

where

α = development growth parameter (the larger the α the more effective is the development program).

M= cumulative MTBF (hrs)

t = testing time in hours

- Such a model would help to:

  - assess the effectiveness of the development process;

    The value of α is interpreted as:

$\alpha > 0.4$	Reliability has top priority; very effective development program
$\alpha = 0.3 - 0.4$	Reliability has high priority
$\alpha = 0.2 - 0.3$	Routine attention paid to reliability, important failure modes investigated and analyzed
$\alpha < 0.2$	Reliability has low priority

  - estimate how much more development effort is needed to ensure a reliability target is reached, or
  - estimate the final reliability of a product for a given amount of development effort.

Reliability Growth Experience from Other Technology Development Suggest a Linear Log-Log Relationship Between Failure Rate and Testing Time

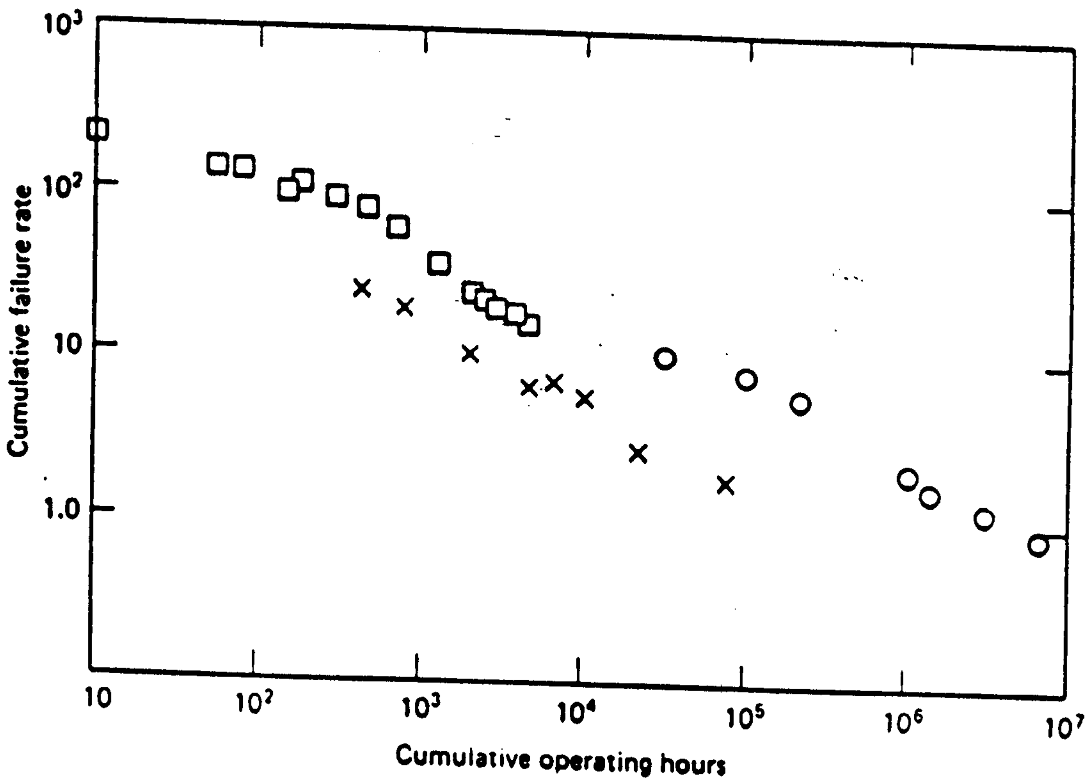


Figure 10.22 Some of the data quoted by Duane to support a linear log-log relationship during development.
□ Aircraft generators.
× Complete aircraft jet engine (during early stages of introduction into service).
○ Complex hydromechanical device

An Aggressive Development Program Leads to Less Test Time Required and Faster MTBF Growth

- The MTBF at the end of the development process will be somewhat higher than M_c because the early design has been modified to reduce the probability of certain failure modes that manifested themselves early on.

- The instantaneous failure rate (λ_i) at time t is expressed as:

$$\lambda_i = \frac{dn}{dt}$$

where n = number of failures at time t, and

$$n = \frac{t}{M_c} = \frac{t^{1-\alpha}}{A}$$

Therefor $$\lambda_i = \frac{d(t^{1-\alpha}/A)}{dt} = \frac{1-\alpha}{A} t^{-\alpha}$$

and $$M_i = \frac{1}{\lambda_i} = \frac{1}{1-\alpha} A\, t^{\alpha}$$

Requirements on Testing Time for Achieving a Blanket MTBF of 5 Years as a Function of Development Factors and A*

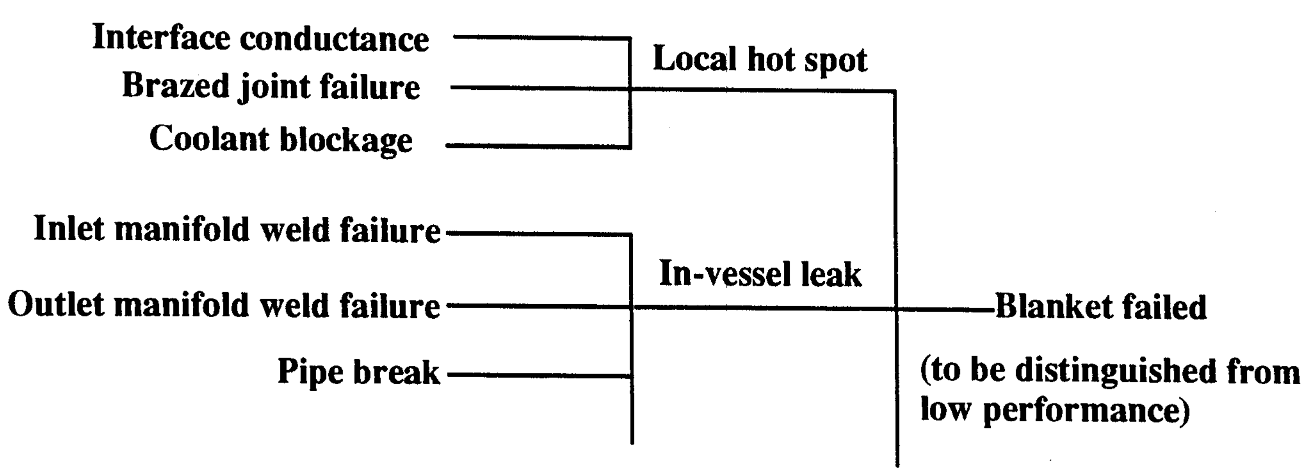
Target MTBF (M_i) for DEMO Blanket	Further Testing Time, Hours (Years) A = 100	
	$\alpha = 0.5$	$\alpha = 0.3$
4.38×10^4 hours (5 yrs)	4.8×10^4 (5.5)	1.9×10^8 (2.2×10^4)

* MTBF of Blanket at 1 hour of testing

A Process to Address Blanket Reliability by Defining Tests Through Fault Tree Analysis

The process involves:

- Breaking the blanket down to the level of constituents- pipes (straight pipe, bends and welds), manifolds, cladding,etc.
- Identifying all possible failure modes of the blanket on the lowest level of breakdown
- Setting -up the event trees representing the sequence of effects following on the primary failures up to the final consequence
- Setting-up the fault tree representing the outage logic
- Assessing the occurrence rates of the various failure modes identified
- Identifying those constituents which contribute most to failure rate
- Defining reliability life tests for those constituents



HIGHLIGHT OF TEST PROGRAM ON VNS

Scope of Testing in VENUS

Information Obtained from Basic Device

- Divertor Operation
- Heating and Current Drive Systems
- Protective Armor and Limiters
- Neutronics and Shielding
- Magnet Systems
- Tritium Processing

Testing in Specialized Test Ports

- Materials Test Module
  - Material Properties Specimen Matrix
- Blanket Test Modules
  - Screening Tests
  - Performance Verification
  - Reliability Growth
- Divertor Test Modules
  - Engineering Performance
  - Design Improvements and Advanced Divertor Testing
- Current Drive and Heating Launchers

Demonstration of Remote Maintenance Operations

Primarily through frequent changeout of various test articles

Test Program Phases

Basic device checkout

- achieve reliable plasma performance
- observe basic machine operation
- PIC performance characterzization

Screening test campaigns

- rapid removal and replacement capability
- increasing fluence and machine availability
- assess and reduce number of design options
- benchmark non-fusion results

Performance verification campaigns

- integrated module behavior
- modest fluence exposure (neutron effects)

Reliability growth

- identify failure modes and effects
- test/fix/improve
- statistical reliability data
- develop confidence in DEMO components

Test article types

Material Specimens (1 cm × 1 cm)

– large number of coupons placed in a materials test module

Elements and Submodules (10 cm × 10 cm)

– grouped into modules with limited independent control and limited on-line instrumentation

Modules (1 m × 0.5 m)

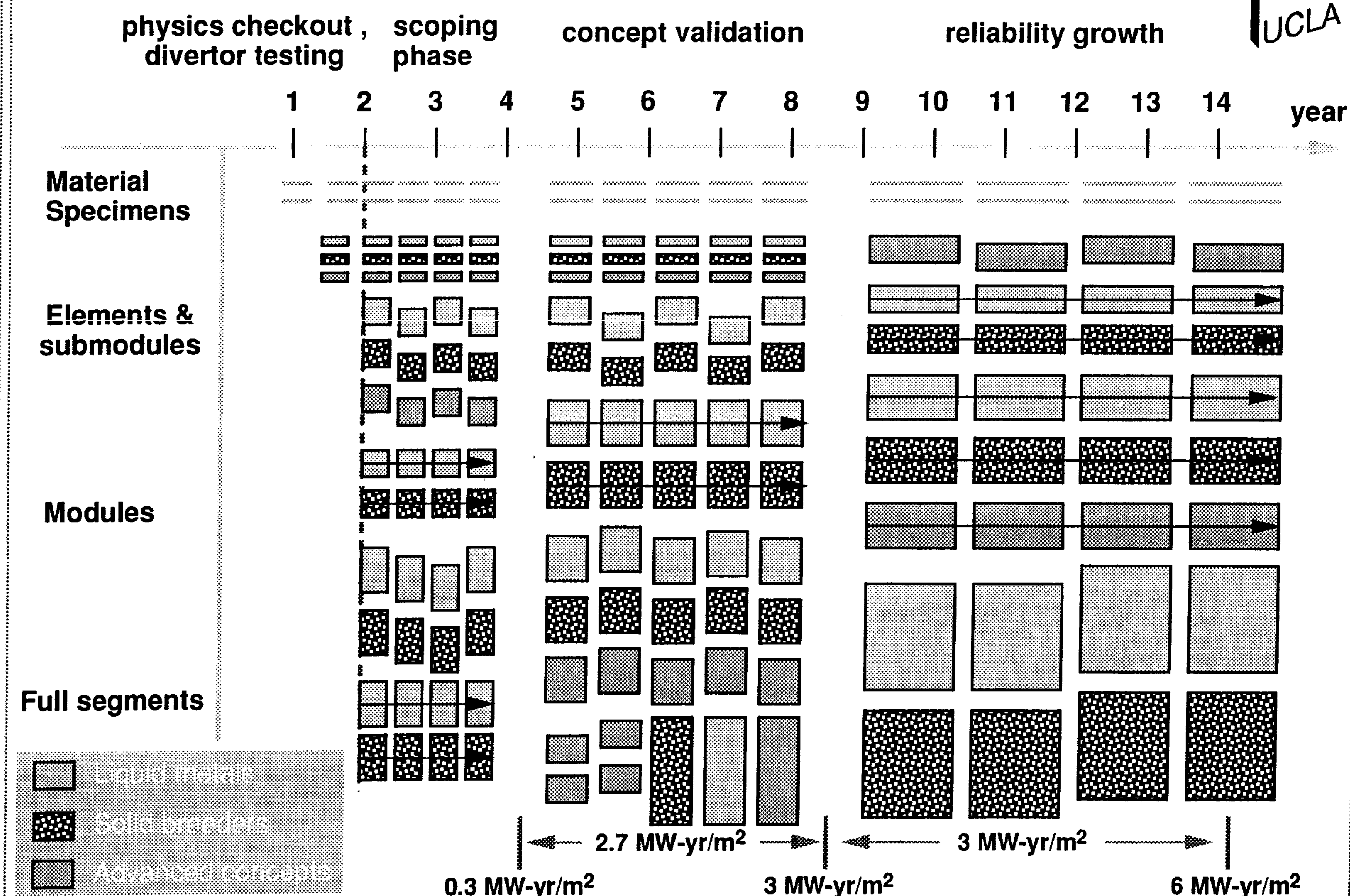
– separate services

– full prototype simulation

Segments (1 m × 5 m)

– incorporates complete reactor integration

Blanket Test Sequence for VNS Nuclear Test Facility



Liquid Metal Blanket Test Types

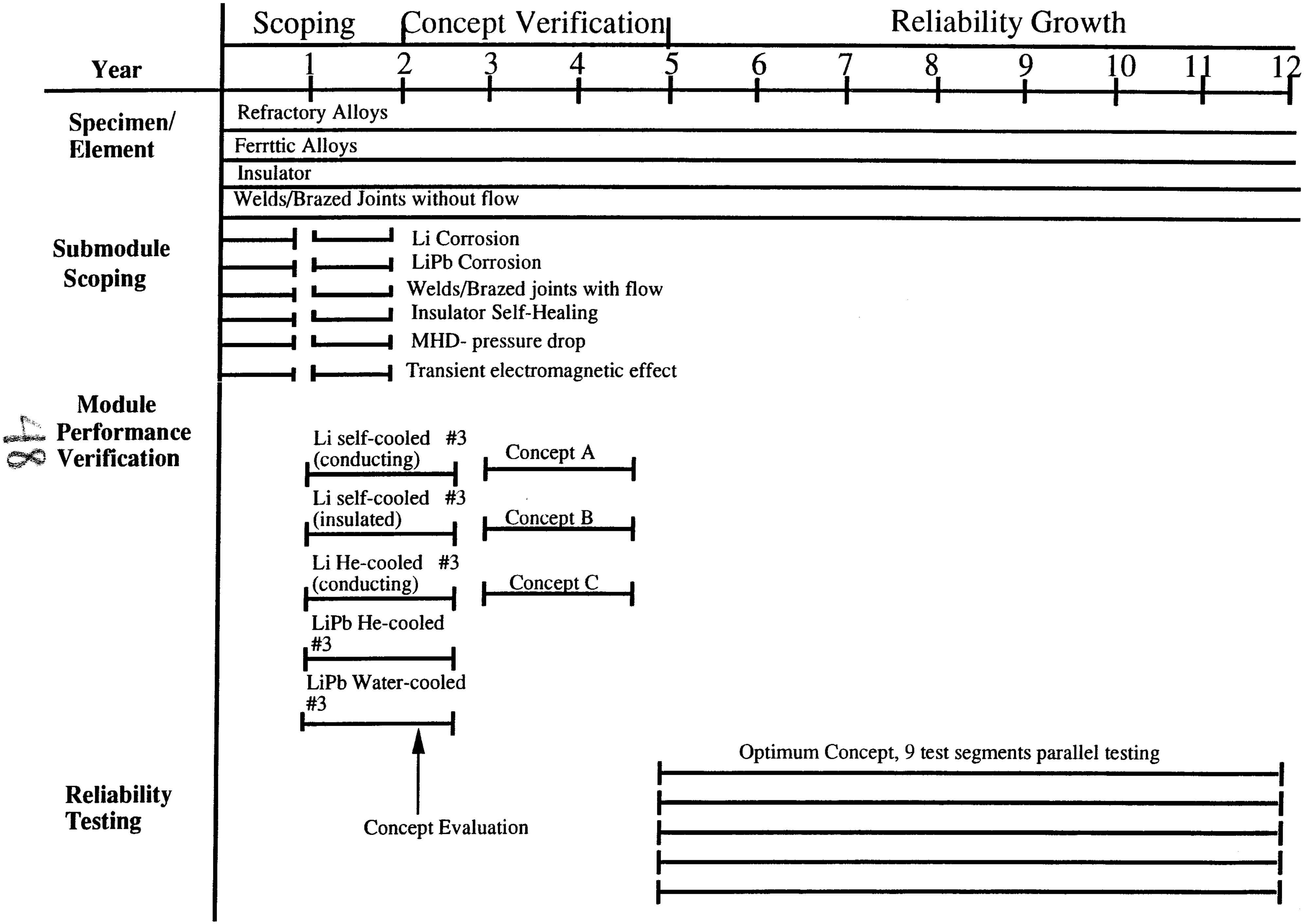
- Specimen/Element Testing
  - Irradiation effects on material properties and physical integrity
  - Test will continue during all of testing phase, but specimens will be pulled or replaced frequently.
  - Data provides input to module and sector test design and operation.
  - Data will be compared to laboratory and fission reactor data.

- Submodule Testing
  - Scoping Test
  - Tests will address critical issues and short term failure modes in related with various design concepts

- Module Testing
  - Performance Validation Tests
  - Integrated performance
    - MHD/Thermal Hydraulics
    - Mass Transfer
    - Thermo-mechanical Behavior
    - Failure Mode Scoping
    - Tritium Recovery/Containment
    - Transient Behavior
  - Results of module tests will be used to select concepts/design for segment tests and provide long term data for DEMO blanket

- Segment Testing
  - Prototypic Configuration/Maintenance
  - Prototypic Poloidal and FW Boundaries
  - Reliability Testing

Example of Test Sequence for Liquid Metal Blankets



Liquid Metal Test Matrix

Tests	Typical Test Article Sizes (Toroidal x Poloidal x Radial; cm)	Number of Test Articles
Basic tests (Specimen/Element)		
Structural material irradiated properties	2.54 x 1 x 2.54	5000
Insulator material irradiated properties	2.54 x 1 x 2.54	500
Welds/brazed joints behavior experiments	10 x 10 x 10	100 (material x shape x fluence)
Multiple-effect/multiple interaction tests (Submodule)		
Corrosion verification	25 x 25 x 25	2x2x3 (material x velocity x temperature x redundance)
Welds/Brazed joints with flow	25 x 25 x 25	5 x 2 x 3 x 5 (geometry x velocity x temperature x redundance)
Insulator self-healing	25 x 25 x 25	5 x 2 x 3 x 5 (geometry x velocity x temperature x redundance)
MHD pressure drop	25 x 25 x 25	5 x 3 x 5 (geometry x velocity x redundance)
Transient electromagnetic effect	Variable x 25 x 25	5 x 5 (toroidal dimension x redundance)
Performance Validation (Module)		
Integrated performance test - stage 1	100 x 100 x 50	5 x 3 (concept x redundance)
Integrated performance test - stage 2	100 x 100 x 50	3 x 3 (concept x redundance)
Reliability Growth	100 x 100 x 50	9
Total Test Area for LM (m^2)	15	

Solid Breeder Testing Strategy

- Parallel and Sequential Tests
- Basic Tests
  - Property measurements on specimens over lifetime of VNS
- Single-Effect Tests
  - Small-scale tests over lifetime of VNS
  - Help calibrate non-fusion tests
  - Code and model validation
- Submodule Tests
  - Concept screening
- Module Performance Verification Tests
  - Four modules selected from concept screening results
- Qualification Test
  - Five modules of selected configuration from performance verification results for reliability growth
- Sector Test
  - Final fully integrated performance verification test on selected configuration
- Lifetime Test
  - Make the most use of fluence by inserting one or two modules from the start to the end of operation

Solid Breeder Test Matrix

- Revisit Earlier Work with More Detailed Assumptions for Test Matrix Estimates

- Example for Basic Tests:

  - Number of specimens for solid breeder irradiated properties

    4 properties
    4 solid breeders
    2 material forms
    3 porosities
    4 temperature levels
    4 fluence levels
    2 for duplication

    TOTAL: 3072

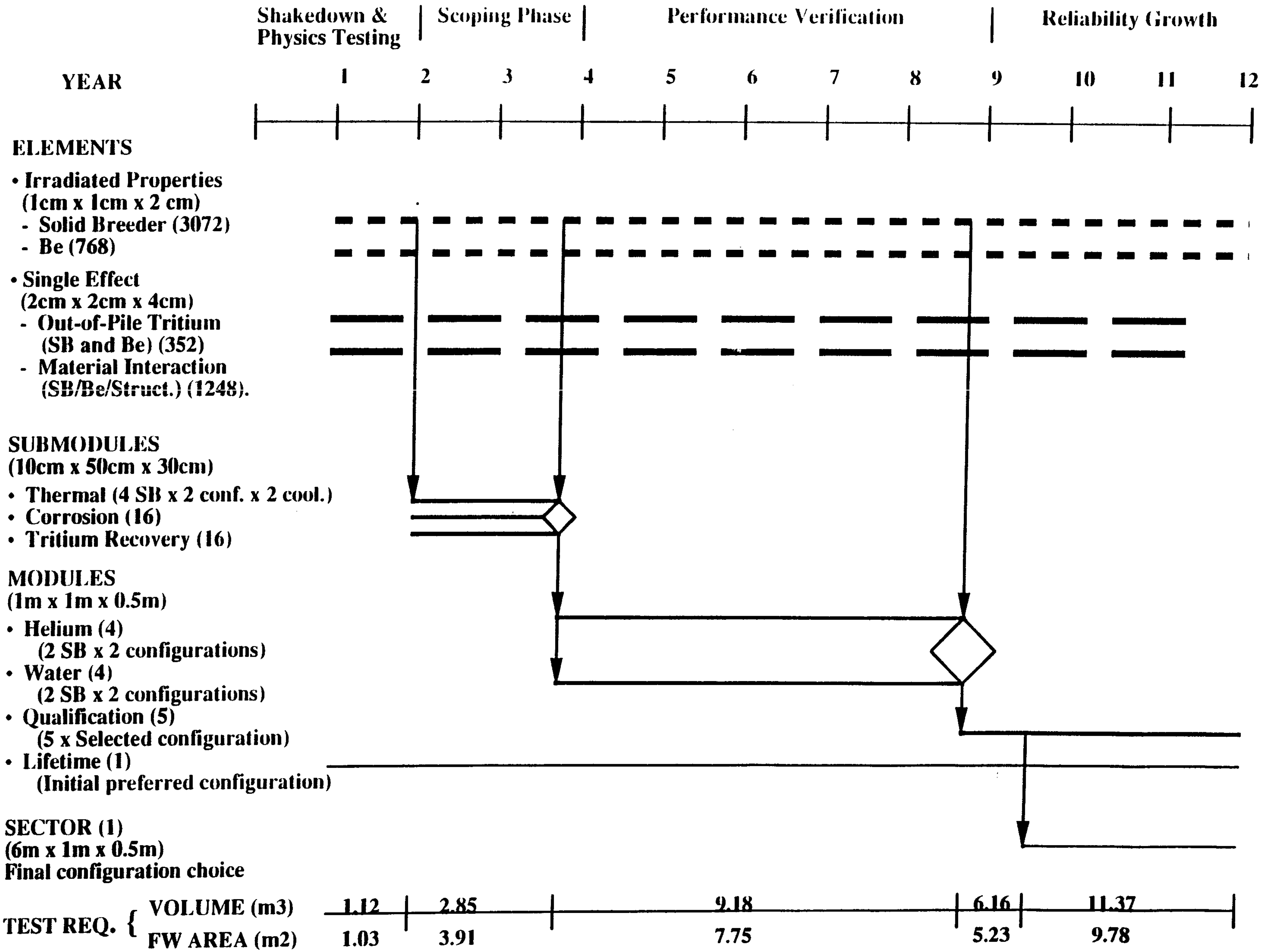
  - Specimen size 1 cm x 1 cm x 2 cm

  - However, each specimen would need to be contain inside a shell to isolate it from its neighbors and to set the appropriate boundary conditions (e.g. neutronics or temperature) (N.B For larger test submodules and modules, space would also be required for coolant, purge lines and diagnostics, i.e to service the test submodule or module)

  - Thus, assume test volume required per specimen 2 cm x 2 cm x 3 cm

  - Set required test area at the first wall based only on highest fluence condition

EXAMPLE TEST SEQUENCE FOR SOLID BREEDER BLANKETS



EXAMPLE SOLID BREEDER TESTS IN VENUS

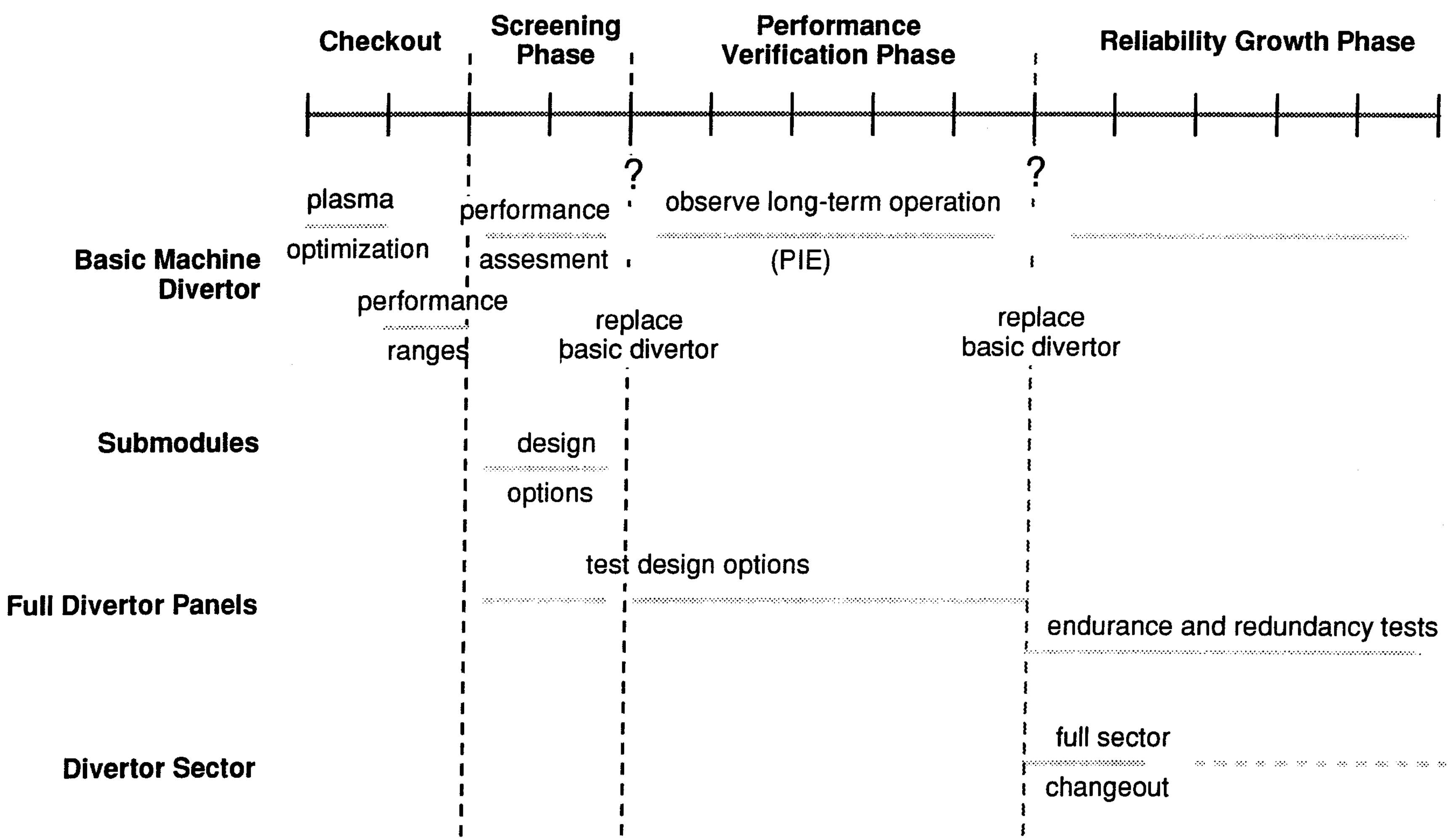
Tests	SB (SBxformxpor)	Be Form (formxpor)	Structure	T	Fluence	Dupl.	Total	Element Size (Test Size)	Volume m^3	FW Area m^2
Basic Tests										
Solid breeder irradiated properties (4 properties)	4 x 2 x 3			4	4	2	3072	1 x 1 x 2 cm (2 x 2 x 3 cm)	0.037	0.077
Be irradiated properties (4 properties)		2 x 3		4	4	2	768		0.009	0.019
Single Effect Tests										
Solid breeder tritium recovery	4 x 2 x 2			4	4	1	256	2 x 2 x 4 cm (3 x 3 x 5 cm)	0.012	0.014
SB/structure interaction	4 x 2 x 1		3	4	4	1	384		0.013	0.022
Be tritium inventory &rec.		2 x 3		4	4	1	96		0.004	0.005
SB/Be interaction	4 x 2 x 1	2 x 1	3	4	4	1	768		0.035	0.043
Be/structure mechanical inter.		2 x 1	3	4	4	1	96		0.004	0.005

EXAMPLE SOLID BREEDER TESTS IN VENUS

Tests	SB	Be	Structure	Config.	Total	Element Size (Test size)	Volume m^3	FW Area* m^2
Multiple Effect Tests (submodule)								
Thermal:								
water	4	1	1	2	8	10 x 50 x 30 cm	0.288	0.48
helium	4	1	1	2	8	(15 x 60 x 40 cm)	0.288	0.48
Corrosion:								
water	4	1	1	2	8		0.288	0.48
helium	4	1	1	2	8		0.288	0.48
Tritium Recovery and Permeation:								
water	4	1	1	2	8		0.288	0.48
helium	4	1	1	2	8		0.288	0.48
Integrated Tests:								
Module:								
Full module performance verification:								
water	2	1	1	2	4	1 x 1 x 0.5 m	4.03	3.36
helium	2	1	1	2	4	(1.2 x 1.2 x 0.7 m)	4.03	3.36
Qualification (5 x selected configuration)	1	1	1	1	5		5.04	4.2
Lifetime (1 x initial preferred conf.)	1	1	1	1	1		1.01	0.84
Sector Prototypical full sector test	1	1	1	1	1	6 x 1 x 0.5 m (6.5 x 1.2 x 0.7 m)	5.21	4.55

* Preliminary assumption is that all submodules and modules require plasma interface. FW test area estimates are thus quite conservative.

Example Test Sequence for Divertors



Divertor Testing Possibilities in VNS

Groundrule:

In VNS, stable and reproducible plasma conditions are important for the mission. (Basic divertor operation should not be affected by testing).

Fixed Parameters

- plasma-facing material in the divertor
- divertor overall geometric envelope

Test Parameters

- coolant composition and conditions
  (temperature, pressure, chemistry, tritium concentration & chemistry)
- heat sink material (copper alloys, refractory alloys, carbon, Be)
- channel configuration (fins, roughening, flow paths, ...)
- method of bonding plasma-facing material to coolant
  - monoblock
  - duplex braze
  - liquid braze

Divertor Test Summary

1. Basic Machine Divertor Test Schedule

Initial performance verification
thermal hydraulic and mechanical behavior
tritium balance

Operating range demonstration and transients
off-normal demonstration of thermal hydraulic and mechanical

Long-term operation
observe thermal-hydraulic and mechanical behavior
observe tritium behavior and loop chemistry
occasional removal and replacement of panels for PIE

2. Alternate and Advanced Design Tests

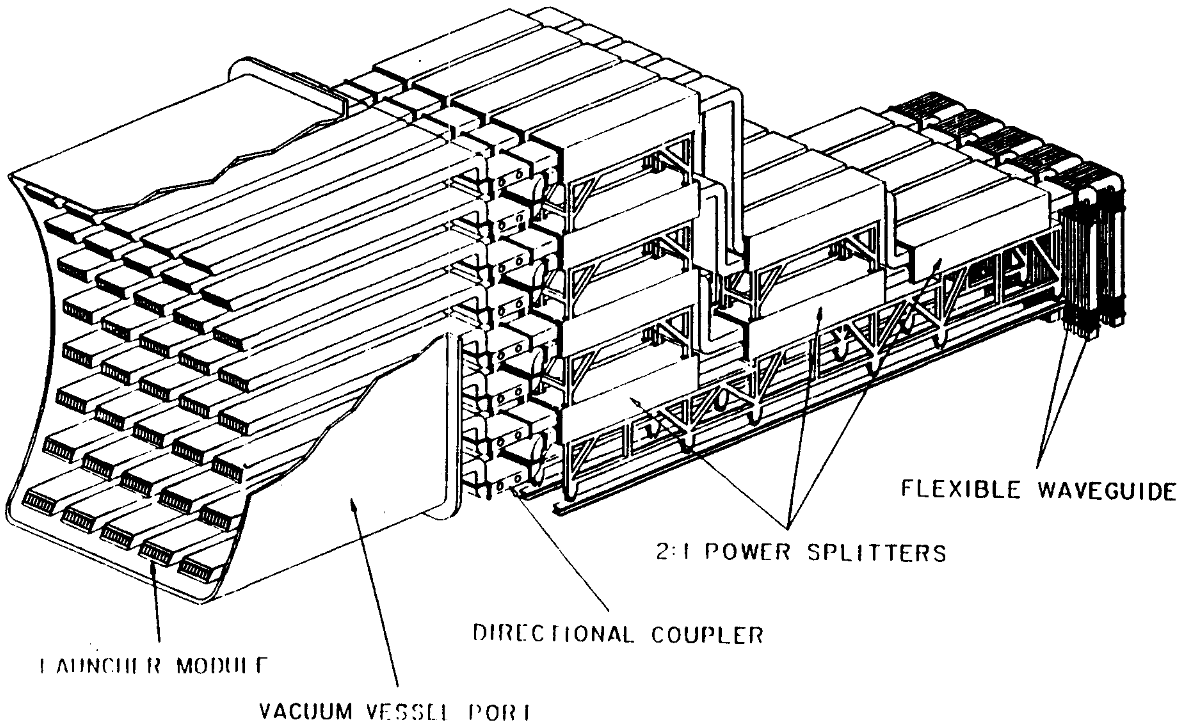
Test Port Submodules (25 cm × 25 cm)
Materials Combinations × Configurations ~ 10
Test Redundancy ~3 → 30 submodules

Full Divertor Panel (1 m × 1 m)
Reduce design options to 2–3
Reduce redundant tests to 1–3
→ ~5 total

Full Divertor Sector
1 or 2 (possibly)

Heating and Current Drive Systems Test Program

The primary nuclear component is the launcher array (~1.5 m × 2 m)



ITER LOWER HYBRID CURRENT DRIVE LAUNCHER

Key features:

- very close to plasma
- complex, actively-cooled structures (this is a **high-heat-flux** component)
- electrical insulators at the vacuum vessel with simple streaming paths
- Be cover and protective limiters needed
- open paths for particle and radiation transport

Changes in performance are likely due to nuclear effects:

- electromagnetic spectrum degradation
- reduced coupling to the plasma
- thermomechanical issues
- shielding effectiveness

Observations:

- waveguides and launchers are important nuclear components, requiring a substantial development and testing effort
- at present, nuclear aspects of heating and current drive seem to be ignored

DESIGN CONCEPTS

FOR VNS

Design Concepts For VNS

- VNS must be a Magnetic Fusion Device
  Plasma is the only credible means at present to generate 14 MeV neutrons at a rate $>10^{19}$n/s

- A Tokamak: Appears to offer the best potential for VNS

  - Driven, Low Q, Plasma based on present data base
  - Experience from Large Physics Devices (e.g. JET, TFTR, JT-60 U, D-IIID)
  - Additional Technology data base required is part of what is being developed under ITER R&D

- Trade off studies have been carried out in the US for a Tokamak VNS. Attractive Design Envelope to meet VNS mission/objectives at a reasonable cost exists.

Cost depends on:
  - Desired Wall Load
  - Normal Conducting Versus Superconducting Magnets
  - Current Drive Capability

Suggested Ground Rules for Evolving VNS Design Concept

- Cost < 0.5 ITER
  (lower cost is encouraged)

- Low Fusion Power (< 400 MW)

- Surface Area at First Wall for testing
  > 10 m^2

- Higher Wall Load
  > 1MW/m^2 (prefer 2 if possible)

- Design for Maintainability and Higher Availability
  Duty Cycle x Availability > 0.3

- No Breeding Blanket
  Avoid use of unproven technologies

- Maximum Site Power Requirements < 700MW

Example of VNS Tokamak Design

[Examples only Based on Conservative Assumptions; Trade off Studies are Presented Later; More Effort is Necessary to Select an optimum design]

	Normal Conducting	Superconducting
Average Neutron Wall Load (MW/m^2)	1.0	1.0
Major Radius, M	2.83	5.52
Aspect Ratio	3.4	4.2
Axial Magnetic Field, T	7.1	7.2
Plasma Current, VA	6.2	7.9
Total Fusion Power, MW	160	500
Current Drive Power, MW	60	110
Inboard Shield thickness, m	0.2	0.9
Q	2.7	4.9
TF Resistive Power, MW	500	N/A
Power Operating Cost (M$/yr) (at 30% availability)	90	35
Direct Cost (B$)	1.9	2.5

SMALL TOKAMAK VNS ENVELOPE ENCOMPASSES A RANGE OF REASONABLE EXTRAPOLATIONS AND COSTS (6/93)

	ITER EDA	S/C Shield	N/C Multi-Turn Shield/Support	N/C Multi-Turn No Inner Shield		N/C Single-Turn No Inner Shield	
Neutron wall load ($MW \cdot m^{-2}$)	2.0	1.1	1.0	1.0	2.0	1.0	2.0
Major radius, R_0 (m)	7.75	4.64	2.6	1.52	1.74	0.91	0.97
Minor radius, a (m)	2.8	1.05	0.84	0.6	0.64	0.6	
Plasma current, I_p (MA)	25	6.4	6.8	6.3	7.3	6.0	6.8
External toroidal field, B_{t0} (T)	6.0	7.7	6.7	6.8	8.0	3.6	4.7
Drive power, P_{drive} (MW)	0	155	60	35	67	24	33
Fusion power, P_{fusion} (MW)	3170	400	150	65	158	42	90
Site power, peak/s.s. (MW)	800/400	400	700	690	700	230	330
Direct-access test area (m)	TBD	110	52	21	23	17	17
Direct cost relative to ITER	1.0	~0.48	~0.45	~0.25	~0.40	~0.14	~0.16

BASED ON A COMMON SET OF PHYSICS AND ENGINEERING ASSUMPTIONS.

[From Summary of IEA Workshop; Moscow July 12-18, 1993]

TABLE 2. VNS Options and Key Parameters Based on Mirror and FRC

CONCEPT	FEF-II[a]	GDT-2[b]		GDT-3[b]	FRC-VNS[c]
Average neutron loading (MW/m^2)	3.5	3.9	–	2.5	13.5
Equivalent major radius, $L_p/2\pi$ or R_0 (m)	$3/2\pi$	$10/2\pi$	–	$10/2\pi$	$5/2\pi$
Plasma (minor) radius, a (m)	0.1	0.06	–	0.07	0.84
Magnetic field at plasma, B_{min}/B_{max} (T)	4.16	1.25/25	–	1.8/26	1.8
Plasma drive power, P_{drive} (MW)	36	20	–	15	10
Fusion power, P_{fusion} (MW)	5	3.0	–	2.0	450
Site power required (MW)	84	50	–	50	TBD
Direct access test area (m^2)	1	0.5	–	0.75	15
Tritium consumption rate[d] (kg/yr)	0.1	0.06	–	0.04	3.9[e]

[a] "Characteristics of Mirror Based Neutron Source – FEF," presented by T. Kawabe, Institute of Physics, University of Tsukuba, Japan.

[b] "Plasma Type High Volume 14-MeV Neutron Sources," presented by E. P. Kruglyakov, Budker Institute of Nuclear Physics, Novosibirsk, Russia.

[c] "High Intensity volumetric Neutron Source Based on a Field Reversed Configuration (FRC)," presented by V. N. Litunovsky, D. V. Efremov Scientific Research Institute of Electrophysical Apparatus, St. Petersburg, Russia.

[d] Assuming no tritium breeding in test program, which has an accumulated availability of 30%.

[e] Assuming a tritium breeding ratio of unity for test blanket modules covering the entire accessible test area, and an accumulated availability of 30%.

[From Summary of IEA Workshop; Moscow July 12-18, 1993]

TABLE 3. VNS Options and Key Parameters Based on Tokamak

CONCEPT	ITER EDA[f]	S/C Shield[g]	N/C Shield[g]	H-I_{bs}[h] (Efremov)	N/C No Shield[g]	TK-T[i] (TSP-PPD)	N/C Single-Turn[g]	MTF[j] (Culham)
Neutron wall load (MW/m^2)	2.0	1.1	1.0	0.7 - 1.0	1.0 - 2.0	0.8 - 1.2	1.0 - 2.0	1.4
Major radius, R_0 (m)	7.75	4.64	2.6	2.5	1.52 - 1.74	1.5	0.91 - 0.97	0.53
Minor radius, a (m)	2.8	1.05	0.84	0.63	0.6 - 0.64	0.5	0.6	0.33
Plasma current, I_p (MA)	25	6.4	6.8	4.1 - 4.5	6.3 - 7.3	3.0 - 3.5	6.0 - 6.8	6.9
Magnetic field, B_{t0} (T)	6.0	7.7	6.7	6.8 - 7.5	6.8 - 8.0	3.5 - 4.2	3.6 - 4.7	2.4
Drive Power, P_{drive} (MW)	0	155	60	50	35 - 67	30 - 40	24 - 33	20
Fusion power, P_{fusion} (MW)	3170	400	150	90 - 130	65 - 158	35 - 45	42 - 90	20
Site power, peak/s.s. (MW)	800/400	400	700	500 - 700	690 - 700	TBD	230 - 330	100
Direct access test area (m^2)	TBD	110	52	30	21 - 23	TBD	17	6
Tritium consumption[k] (kg/yr)	TBD	5.0	1.7	1.3 - 1.9	0.8 - 2.0	TBD	0.4 - 1.0	0.2

[f] ITER-EDA information as of May 1993.

[g] "Initial Design Boundaries and Parameters of Small Tokamak VNS Envelope," presented by M. Peng, Oak Ridge National Laboratory, USA.

[h] "VNS on the basis of the High Bootstrap Fraction Tokamak," presented by A. B. Mineev, D. V. Efremov Scientific Research Institute of Electrophysical Apparatus, St. Petersburg, Russia.

[i] "The Compact Volumetric Neutron Source on the Tokamak Basis (TRINITI – "Kurchatov Institute" Version)," presented by S. V. Mirnov, Troitsk-Kurchatov Institute, Russia.

[j] "Tight Aspect Ratio Tokamak Neutron Source," presented by T. C. Hender, Culham Laboratory, Abingdon, UK.

[k] Assuming tritium a breeding ratio of unity for test blanket modules covering the entire test area for an achieved availability of 30%.

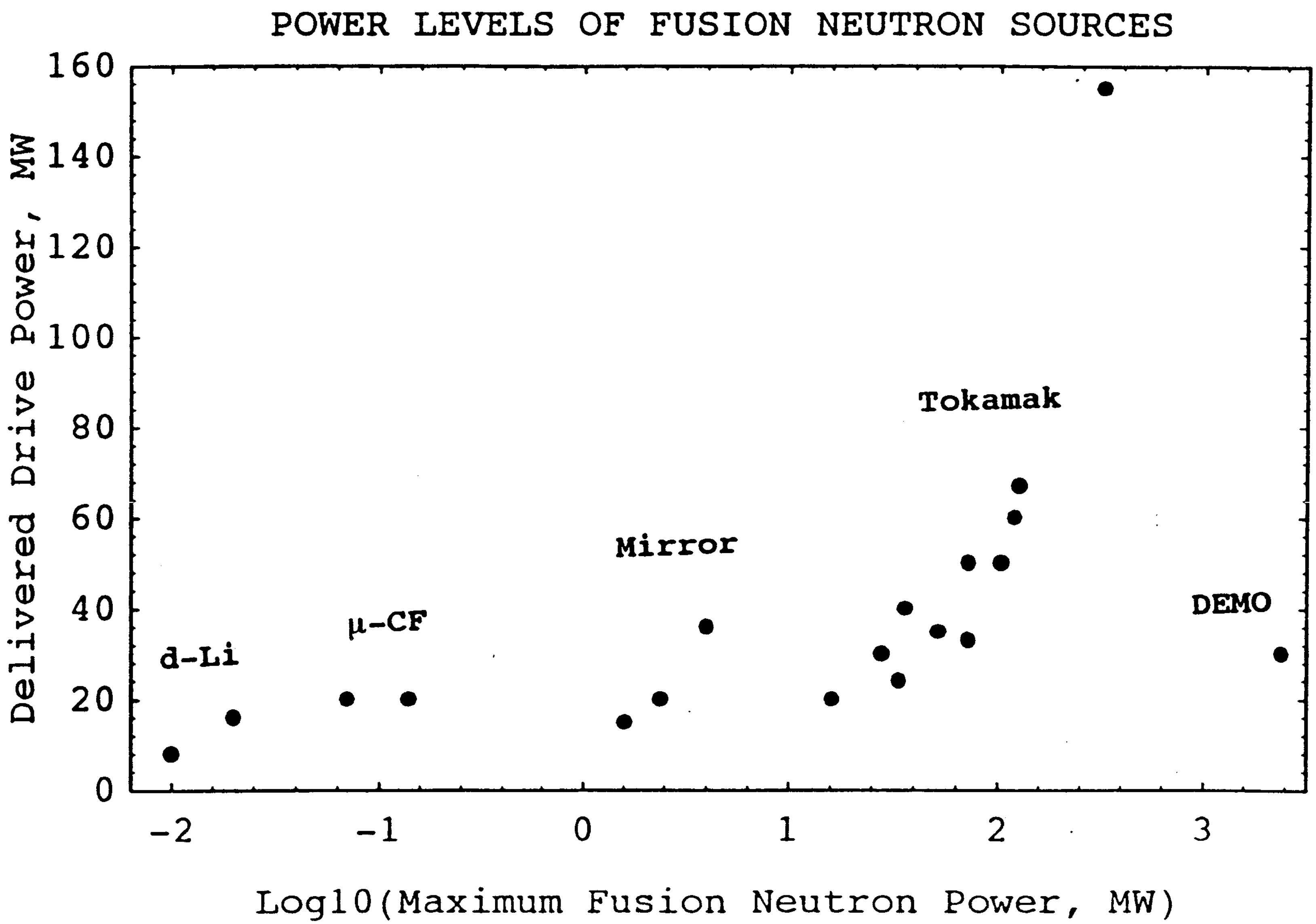


Figure 1. Maximum fusion neutron power produced and the required drive power delivered to the plasma target for the VNS concepts presented at the workshop ("•" representing values from Tables 2 and 3). The values for a DEMO, and the high-flux neutron sources based on d-Li target and μCF are included for contrast.

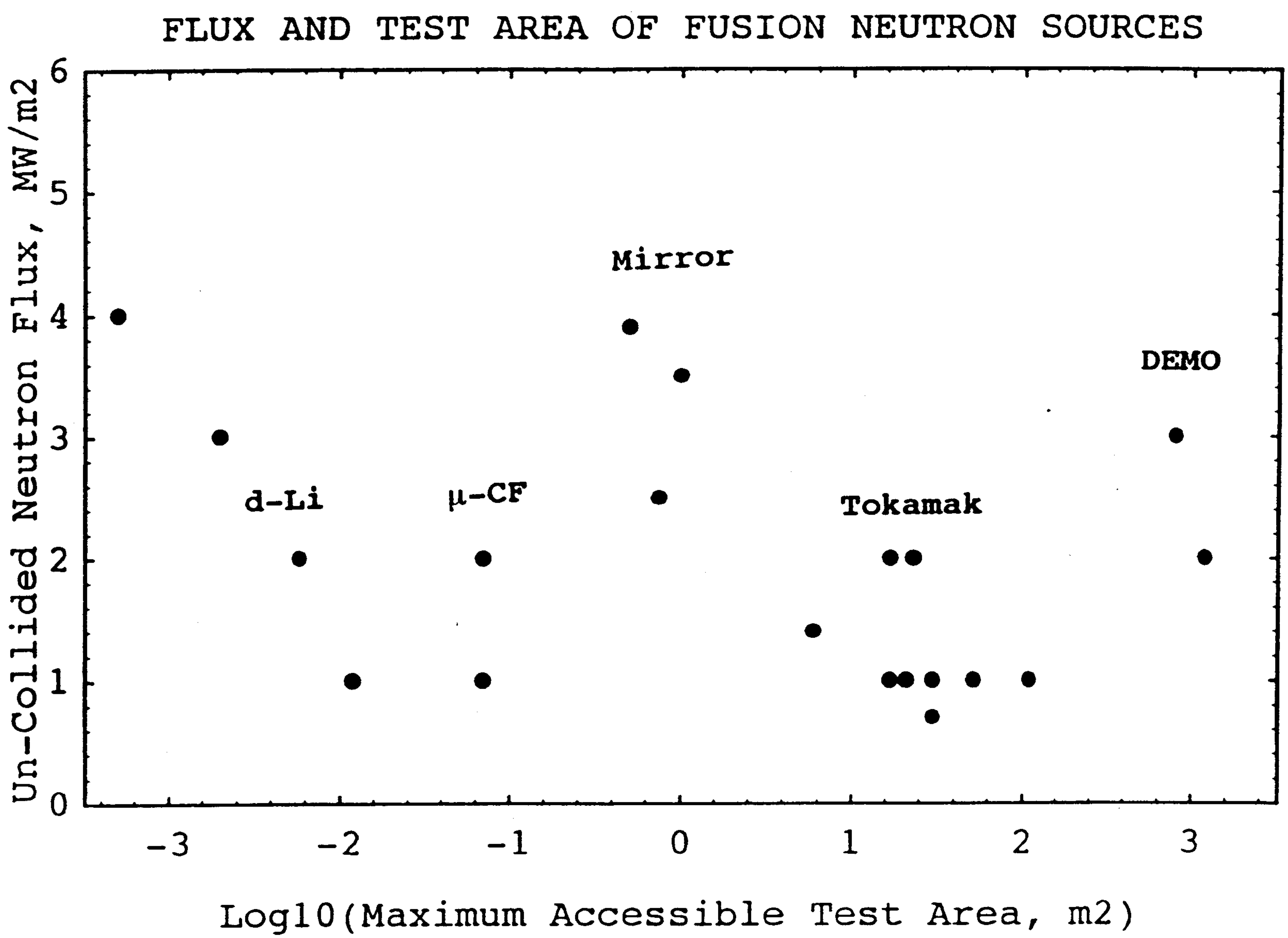


Figure 2. Maximum accessible test area and the un-collided neutron loading averaged over the test area for the VNS concepts presented at the workshop ("•" representing values from Tables 2 and 3). The values for a DEMO, and the high-flux neutron sources based on d-Li target and μCF are included for contrast.

High Wall Load and High Availability in VNS are Necessary to Achieve Goal Fluence in Reasonable Time

Test	Fluence $MW\text{-}y/m^2$	Wall Load MW/m^2	Machine Time FPY
Scoping Test	0.3	1	0.3
		2	0.15
↓			
Performance Verification	1.0	1	1
		2	0.5
↓			
Reliability Growth	5.0	1	5
		2	2.5

Neutron Wall Load MW/m^2	Machine Time FPY	Calendar Time (years) Duty Cycle x Availability 10%	20 %	30%
1	6.3	63	31	21
2	3.15	31	16	11

List of Issues for VNS Design

- Must design for high availability
  25-35%

- Normal versus superconducting TF coil?
  - Inboard shield requirements
  - Ceramic insulators in N/C coils?
  - Demountable N/C TF coils?
  - Radiation limits

- Divertor heat load

- Current drive

VENUS Study

- DOE's Office of Fusion Energy in USA has initiated in May 1993 a new study called VENUS.

- The focus of the study is evaluation of VNS (Volumetric Neutron Source) as a dedicated facility for testing fusion nuclear components and material combinations. VNS will operate in parallel to ITER to achieve the US National Energy Strategy Goal of DEMO operation by the year 2025

- The first phase of VENUS is Concept Definition Study to
  - determine VNS requirements for fusion nuclear component and material testing
  - define an envelope of key features within which VNS must fit (size, power, duty cycle, availability, cost, etc.)
  - Identify promising design concepts for VNS that fit within the envelope

- Participating Organizations: UCLA, ORNL, LLNL and Others

- VENUS will serve as a mechanism for providing the USA technical input to International VNS activities such as IEA

CHARTER

INTERNATIONAL FUSION MATERIALS TEST FACILITIES STUDY

Bearing in mind the long-standing interest in this area, recognizing the strong recommendation from the Executive Committee for the IEA Implementing Agreement on Fusion Materials (Executive Committee) and noting the communication from the Chair of the ITER Council, the Fusion Power Co-ordinating Committee (FPCC) requests the Executive Committee to take action as follows:

OBJECTIVE: Develop a consensus and appropriate technical and managerial bases for decisions, if any, on two test facilities, i.e. 1) proceeding on the Conceptual Design Activities for an accelerator-based International Fusion Materials Irradiation Facility (IFMIF) that will meet the high flux, high energy ("14 MeV") neutron irradiation needs of the fusion materials programs of the partners, and 2) proceeding with studies that could lead to Conceptual Design Activities for a plasma-based source that could meet the high volume, high energy, neutron irradiation needs of the fusion materials programs of the participants.

APPROACH:

TASK 1: Involve the Russian Federation (RF), through the Associate Contracting Party route, as a full technical partner with interested IEA member partners in these efforts. Initial contact with the RF will be made by the Chair (or Vice-Chair) of the FPCC, after which the Executive Committee shall develop and, with the approval of the Governing Board, formalize the RF collaboration.

High Flux Source:

TASK 2: Develop as a technical approach to a possible international agreement, the design choice, a judgment of feasibility and a possible route of implementation to a single, acceptable design for IFMIF.

High Volume Source:

TASK 3: Review the possibilities and assess the programmatic requirements for a possible, high volume neutron source for future consideration by the interested international participants.

Schedule: The efforts of the Executive Committee should be organized to complete these tasks by October 1993, in anticipation of action on any next steps by the FPCC in January 1994.

IEA Activity on VNS

- The Fusion Power Coordinating Committee (FPCC) requested the IEA Executive Committee on Fusion Materials to study and make recommendations regarding:

  - IFMIF: an accelerator-based international fusion materials facility
  - VNS: high volume source

- A workshop was held in Moscow July 12-18, 1993 with participants from EC, Japan, Russia, USA

- Conclusions from workshop
  i) A volumetric neutron source (VNS) fusion facility is needed to test, develop and qualify fusion nuclear components and material combinations for DEMO
  ii) An attractive range of design options exists for VNS

- Recommendations from workshop
  Recommend IEA initiate VNS study activity with 3 phases (with decisions to proceed or terminate at the end of each phase)

<u>Phase 1</u>: Concept definition (2 years)

- Develop detailed statement of mission and objectives
- Elucidate detailed test requirements
- Identify envelope of design concepts, evolve the concepts to a level sufficient for making selection
- Select design concept

<u>Phase 2</u>: Conceptual Design (2 years)

<u>Phase 3</u>: Engineering Design (3 years)

Summary

- VNS (Volumetric Neutron Source) is a fusion facility, which operates parallel to ITER, for testing, developing and qualifying fusion nuclear components and materials for DEMO

- VNS, together with ITER and IFMIF, provide an optimum cost effective path for timely development of DEMO

- Requirements on VNS to effectively perform testing of nuclear components and materials have been identified. Examples are:
  - Neutron Wall Load: 1-2 MW/m^2
  - Neutron Fluence: 4-6 $MW \cdot y/m^2$
  - Plasma Burn Mode: Steady State (or long pulse)
  - Availability: 25-35%
  - Test Area at first wall: 10-30 m^2

- Programmatic constraints suggest that VNS capital cost be kept below one third to one half of ITER

- Fusion Power in VNS should be kept below 400 MW to minimize tritium consumption and avoid the need for breeding blanket

- VNS should rely on present day physics and technology

- VNS will help reduce the Technological Burden on ITER; e.g. eliminating the need for high fluence (operating ITER 3500 MW to high fluence is costly)

- An attractive design envelope for a Tokamak VNS that satisfies the technical and programmatic requirements exists

- Serious International effort is needed to further evaluate the testing requirements and to identify attractive design options for VNS